Met.O.880
METEOROLOGICAL OFFICE

the meteorological magazine

The Senior Meteorological Officer,
R.A.F. Lyneham,
Chippenham, Wiltshire.
SN15 4PZ.

AUGUST 1975 No 1237 Vol 104
Her Majesty's Stationery Office

METEOROLOGICAL OFFICE Met.O.880

THE METEOROLOGICAL MAGAZINE

Vol. 104, No. 1237, August 1975

551.577.23 (425)

INTENSITY–TIME PROFILES OF HIGH-INTENSITY RAINFALL

By J. R. NORBURY and W. J. K. WHITE

(Science Research Council, Appleton Laboratory, Ditton Park, Slough)

Summary. Data from 77 high-intensity rainfall events, observed by rapid-response rain-gauges, have been combined to produce an average intensity–time profile. The shape of the profile is independent of peak rainfall rate. The effect of the rain-gauge sampling time on the profile has been examined.

Introduction. Knowledge of the statistical properties of high-intensity rainfall is needed for estimating the attenuating effect of rain on terrestrial or earth–space millimetric radio links and predicting the performance of some radar systems. It is also useful to workers investigating erosion and drainage.

In many cases, a study of near-instantaneous rainfall rates is required but few experimental measurements have been made. Often, only clock-hourly or daily rainfall amounts are available and methods have been developed in which short-period rainfall rates can be deduced from the longer-period rates. Briggs[1] has derived an average profile of shower intensity at a point against time for the 15 heaviest showers recorded during experiments at Cardington[2] in which use was made of a network of open-scale recording rain-gauges the records from which were analysed to give falls in successive 2-minute intervals, and he gives a method of deducing the high-intensity, short-period falls when records are available for rates up to about 10 mm/h. Briggs and Harker[3] have used the results of a similar analysis from another network at Winchcombe to derive factors which can be applied to estimate, from clock-hourly statistics, the probability of occurrence of short-period rain intensities.

Since late 1969, several rapid-response rain-gauges[4] have been in operation at the Appleton Laboratory, Slough, in conjunction with measurements of the effect of attenuation by rain on experimental millimetric radio links. These gauges produce records of rainfall amounts collected over successive 10-s intervals. On 77 occasions, showers, thunderstorms or the passage of cold fronts produced rainfall with peak values greater than 20 mm/h. Some statistical values derived from these events are presented here.

Selection of events. The term 'rainfall event' or 'event' is used here to mean a fall of rain lasting no more than 15 to 20 minutes, due either to local convective activity or to the passage of a vigorous trough of low pressure, in which the intensity rises from zero or a very small value to a maximum and then drops away to zero again. Some examples of intensity–time profiles, produced directly

from observations of rainfall measured over 10-s intervals are presented in Figure 1. Figure 1(a) shows a shower with a simple structure but Figures 1(b), (c) and (d) show profiles which are complex. They contain a number of individual peaks, some of them quite well defined.

It was decided that two criteria should be met for the inclusion of a profile in the analysis:

(a) the peak intensity had to be greater than 20 mm/h, and

(b) because of the sampling error inherent in the performance of any rain-gauge,[5] a profile must have two consecutive 10–s readings in excess of 20 mm/h.

The duration of an event was easy to define when the rain rate fell smoothly away to a continuous value of zero on either side of a peak value. This happened on 52 occasions on the rising side of a peak and 38 occasions on the falling side of a peak. In the remainder, the duration of the event was taken as defined when the rate fell to or below a preset level for a given length of time. The preset level chosen was 5 per cent of the peak value, or 2 mm/h, whichever figure was the higher, and the length of time was set at 30 s. Only three events would have been split into two if a time of 20 s had been chosen.

For events where the rate did not fall to zero, a small adjustment was made to each point in the profile by subtracting the average rainfall rate over the 30-s periods used to define the duration of the event.

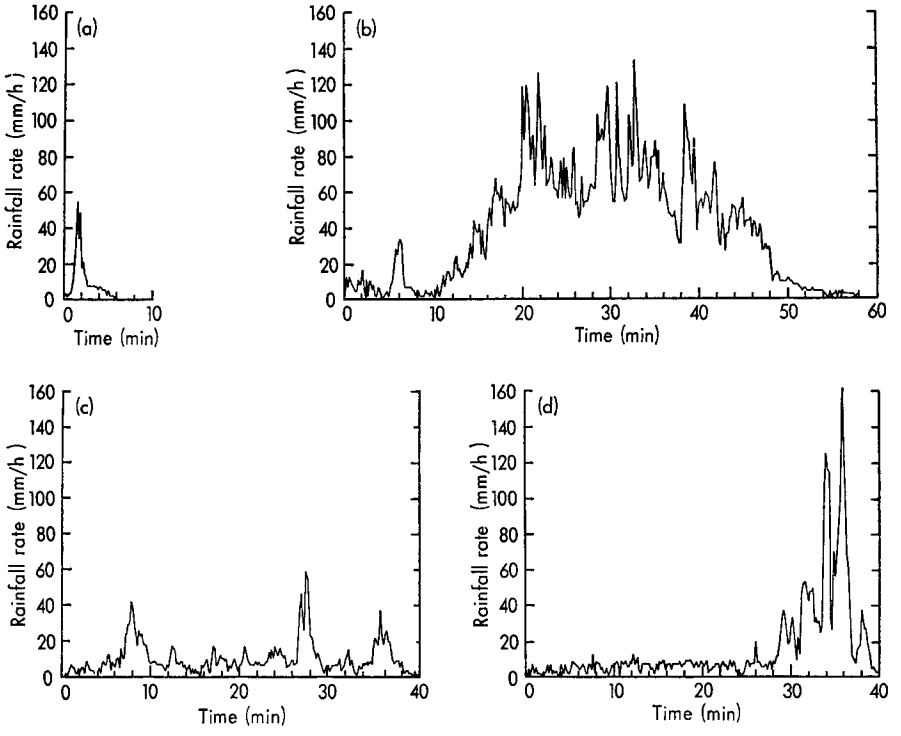

FIGURE 1—EXAMPLES OF SHOWER PROFILES

(a) shows a simple structure, while (b), (c) and (d) are complex structures.

A total of 77 events with peak rates in excess of 20 mm/h satisfied the above criteria. The numbers of events with peak values within specified levels, and for durations of specified lengths, are given in Figures 2 and 3.

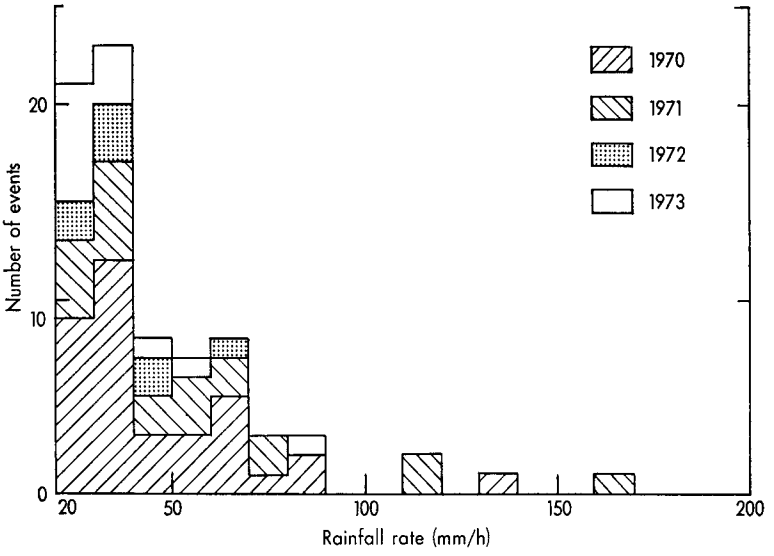

FIGURE 2—NUMBERS OF EVENTS WITH PEAK VALUES WITHIN SPECIFIED LEVELS

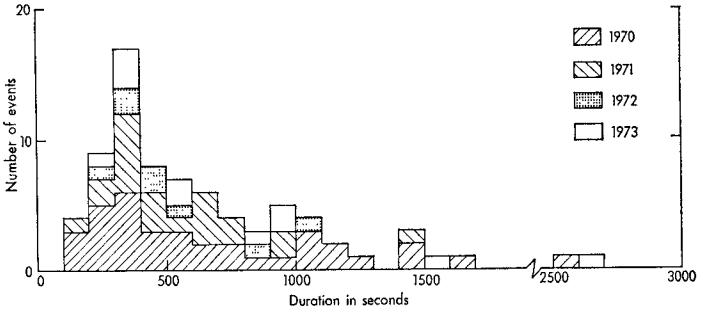

FIGURE 3—DISTRIBUTION OF DURATIONS OF EVENTS

Method of analysis. For each event the intensities in all the 10-s intervals were expressed as fractions of the peak value. The mean profile was then obtained by averaging the fractions at successive intervals of 10 s before and after the peak of each of the 77 events.

To obtain an estimate of the scatter of the values around the mean, the standard deviation (σ) was determined for each 10-s interval.

Intensity–time profiles. The mean profile, and those corresponding to $\pm 1\ \sigma$ are shown in Figure 4 for times from -550 s to 550 s from the peak. The width of the mean profile between points where the intensity is 50 per cent

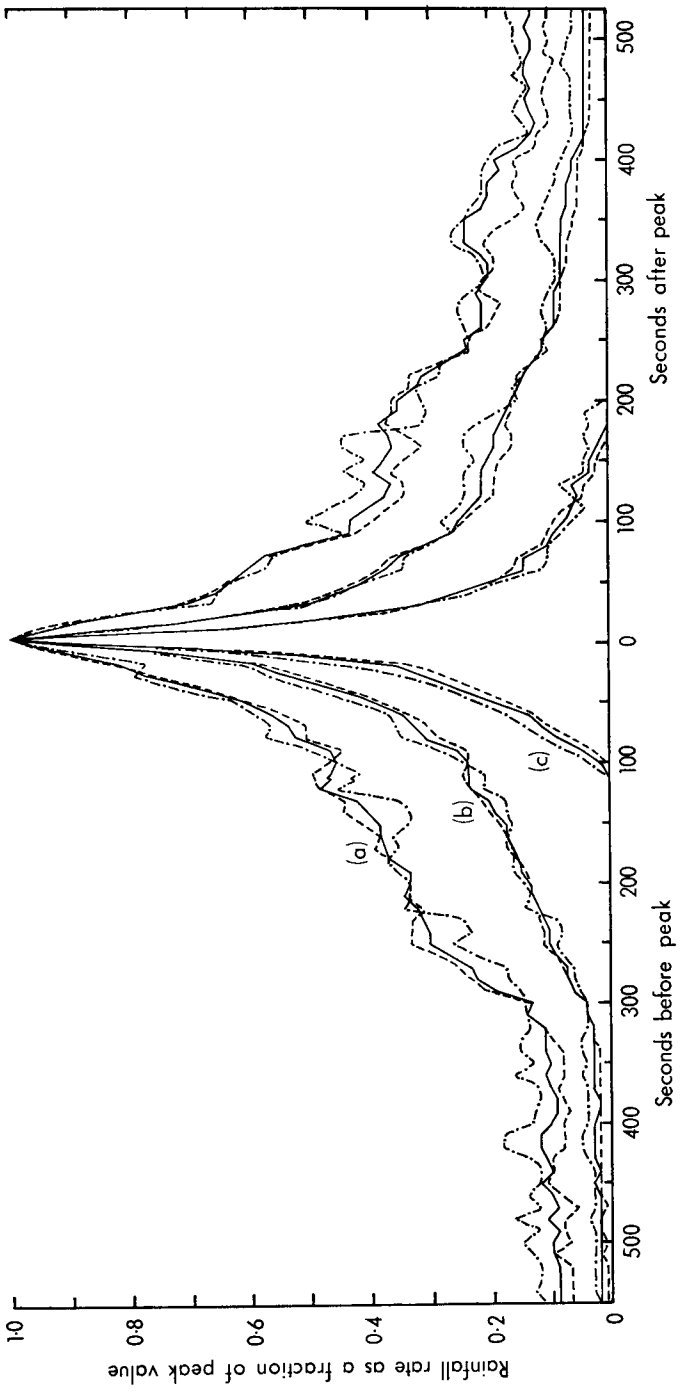

FIGURE 4—MEAN AND STANDARD-DEVIATION PROFILES FOR EVENTS WITH PEAK RATES IN EXCESS OF OR BETWEEN SPECIFIED LEVELS

(a) mean profile + 1 σ
(b) mean profile
(c) mean profile − 1 σ
——— All events — — — Events with peak values in the range 20 mm/h to 50 mm/h
—·—·— Events with peak values in excess of 50 mm/h.

of its peak value—which may be called the 'half-width'—is about 67 s, and the average rainfall rate, using an arbitrary upper limit of 2100 s for the duration of the mean profile, is 9 per cent of the peak value.

The large variations from the mean profile arise from the different spatial extents and speeds of movement of the rain cells, and the fact that a single gauge records profiles along different chords of the various cells. Wind speeds at the 700-mb level for the events included in the analysis range from 3 m/s to over 40 m/s, but the spatial extents of the events are not known.

Variation of mean profile with peak intensity. Figure 4 also shows the mean and standard-deviation profiles for events with peak rates in excess of 50 mm/h, and for events with peak rates between 20 mm/h and 50 mm/h. There is no statistically significant difference between the profiles. This implies that in this range of rates the profile is independent of the peak value.

Too few events have been observed with rainfall rates much in excess of 50 mm/h for one to be able to say whether this independence applies for very intense peak values. For example, only 10 events have been observed with peak rates in excess of 70 mm/h, and this is a small number for statistical analysis. However, the mean profile obtained from these 10 events has the same half-width and the same average rainfall rate as the profile obtained from all 77 showers. This strongly implies that the model profile for events with peaks in excess of 70 mm/h will be the same as that for all others.

Effect of sampling time. The 10-s rainfall rates from the rapid-response rain-gauges have been averaged over longer periods to simulate gauges with longer sampling times. For the present study the results have been averaged to give 1-minute and 2-minute clock values for all events. The results were analysed in the same way as the 10-s data.

For the 1-minute values, events with 1-minute rainfall rate peaks in excess of 20 mm/h were chosen. However, in order to obtain a large enough sample for the 2-minute rates, a figure of 15 mm/h was used. The profiles obtained are shown in Figure 5 together with the 10-s values, and the 2-minute values from the profile derived by Briggs. The 2-minute profiles agree well. The average rainfall rate for the Slough 2-minute profile is 12·5 per cent of the peak value, again in good agreement with the figure of 12 per cent obtained by Briggs.

Conclusions. A mean profile has been derived for the variation with time of intense rainfall observed at a point over an interval of 10 s. It appears to be independent of peak rainfall rate and has a half-width of 67 s and an average rainfall rate of 9 per cent of the peak value. The extent of expected variation from the mean is indicated by the profile giving values for the mean $\pm 1\ \sigma$.

The mean profile derived by simulating a 2-minute rain-gauge is in good agreement with previous work.

Acknowledgements. This work was carried out as part of the programme of the U.K. Science Research Council's Appleton Laboratory and is published by permission of the Director. The authors acknowledge the advice of Mr B. N. Harden during the course of this work and the assistance of Mr G. P. Harris in maintaining the experimental apparatus and in the preparation of the data.

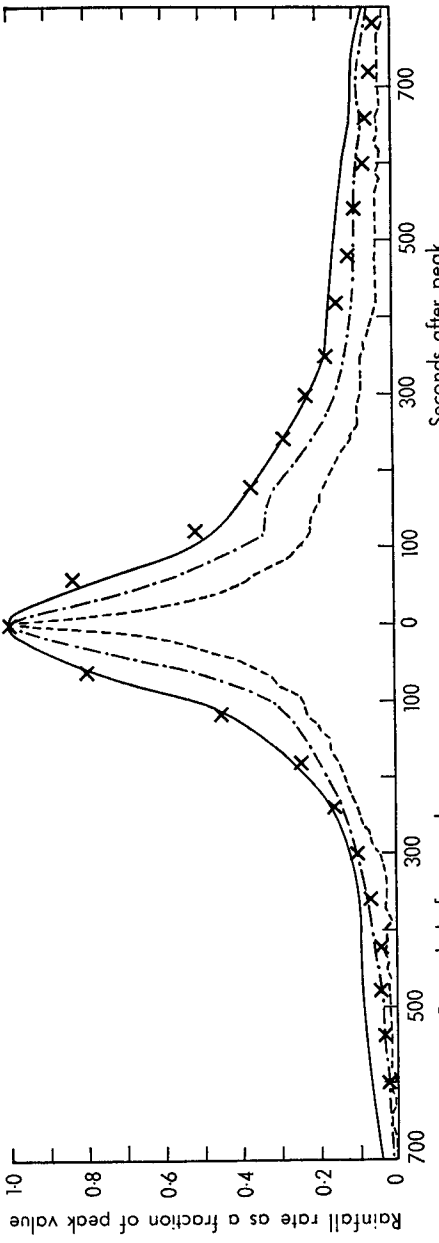

FIGURE 5—INTENSITY–TIME PROFILES FOR DIFFERENT SAMPLING TIMES

— — — 10-s data —·—·— 60-s data ——— 120-s data × × × Briggs's data

REFERENCES

1. BRIGGS, J.; Estimating the duration of high-intensity rainfall. *Met Mag, London*, **97**, 1968, pp. 289–293.
2. HOLLAND, D. J.; The Cardington rainfall experiment. *Met Mag, London*, **96**, 1967, pp. 193–202.
3. BRIGGS, J. and HARKER, J. A.; Estimates of the duration of short-period rainfall rates based on clock-hour values. *Met Mag, London*, **98**, 1969, pp. 246–252.
4. NORBURY, J. R. and WHITE, W. J. K.; A rapid response raingauge. *J Phys*, E, *Scient Instrum, London*, **4**, 1971, pp. 601–602.
5. JOSS, J. and WALDVOGEL, A.; Raindrop size distribution and sampling size errors. *J Atmos Sci, Boston, Mass.*, **26**, 1969, pp. 566–569.

551.507.362.2:551.515.23

A NOTE ON TROPICAL STORMS IN THE ARABIAN SEA, OCTOBER TO DECEMBER 1972

By R. A. EBDON* and W. J. OXLEY*
(Meteorological Office RAF Masirah)

Summary. This paper describes the use made of satellite pictures for detecting and tracking the tropical storms which occurred in the Arabian Sea during the period from October to December 1972. The storm of 19–28 October is described in some detail.

Introduction. There are various definitions of 'tropical cyclones', 'tropical depressions' or 'tropical storms' and the terms themselves are subject to differing interpretations. However, setting aside these differences, it is well known that in an intense tropical storm the surface wind can exceed Beaufort force 12 (64 kt $\approx$ 33 m/s); the weather is often violently disturbed, usually with torrential rain and occasionally accompanied by thunder and lightning. The frequency with which these storms occur varies very considerably over the different oceanic areas in the tropics, reaching a maximum in the North Pacific Ocean and a minimum in the Arabian Sea. These storms often originate just north of the Intertropical Convergence Zone (ITCZ) when it is displaced by at least five degrees of latitude from the equator. It is generally accepted that the sea temperature in the area must be at least 26·5°C.

In the Arabian Sea there are two seasons for tropical storms; firstly when the ITCZ is moving southwards in October to December and, secondly, when the ITCZ is moving northwards in May and June. Pedgley[1] showed that during the months October to December there were 30 storms over the whole Arabian Sea in the period from 1890 to 1950 (an average of one storm every two years). However, in the corresponding months of 1972 there were four storms which were all detected by means of satellite pictures from ESSA 8. Undoubtedly the use of the weather satellite will increase the frequency with which tropical storms are observed but the occurrence of four storms during October–December 1972 was probably not exceptional, since Pedgley[1] suggests that during 1902 five storms were observed over the Arabian Sea area. He also refers to 10 storms in 25 years (1943–67) which approached or crossed the Arabian coast. In October–December 1972 two storms approached the Arabian coast and one of these (19–28 October) even entered the Gulf of Aden, where only three or four storms were experienced during the period 1879–1944.[2]

* Now at Meteorological Office, Bracknell, Berks.

The storm of 19–28 October 1972. This tropical storm was first identified on 19 October and located at approximately 9°N 62°E on the ESSA 8 satellite picture; this provided the only evidence for the existence of a tropical disturbance. Daily pictures from ESSA 8 continued to provide the only information (apart from a few aircraft reports) with the help of which to locate the storm and forecast its progress. The track which it followed is shown in Figure 1. The cloud associated with the storm on 20 October can be seen in Plate I and its subsequent development in Plates II–IV.

The stage of development of the storm was estimated from the appearance and size of the cloud mass on the gridded satellite pictures. An estimate of the maximum surface winds associated with the storm was obtained from a nomogram produced by the Environmental Science Services Administration (ESSA)[3] using stage of development and the diameter of the central cloud mass.

On 19 October the disturbance could only be classified as a dense cloud cluster. By the 21st the cloud mass was at least 6 degrees of latitude in diameter, with moderately concentric cloud bands. Much curved cirrus outflow was visible at the edge of the cloud mass, which was tending to become circular, but no 'eye' was discernible. A Stage X Category 2 storm had developed. Stage X storms are those with a centre within the cloud mass. The category (1–4) is determined from the degree of circularity of the curved and spiral bands. Only Stage X Category 3 and 4 storms have an 'eye'.

For the next two days (21–23 October) the storm continued to enlarge and a band of cloud 1600 kilometres long developed to the east. For about four days (19th–23rd) it moved broadly polewards at an average speed of 3½ knots. It was slow moving on the 23rd, possibly moving eastwards. On the 24th (Plate III) it changed direction and moved quickly westwards, passing south of Ras Asir on the 25th, and into the Gulf of Aden by the 26th. It passed inland near Djibouti on the 27th (Plate IV). The storm averaged about 11 knots during its westward movement. The satellite pictures show that decay was quite rapid from the 25th to the 26th, but that a very dense cloud cluster with a diameter of about four degrees of latitude still remained when the storm crossed the coast on the 27th. This cloud dissipated almost completely by 28 October.

The centre of the storm approached to within about 900 km of Masirah on 24 October, and gave four rather cloudy days, with only a trace of rain on the 23rd—all the rain falling from unstable medium cloud in 20 minutes. At Salalah, where the centre was about 550 km to the south on the 23rd, south-easterly winds reached 40 knots with gusts to 57 knots between 11 and 12 GMT, and visibility was reduced at times to 50 m or less by rising sand. There was a further adjacent sandstorm on the 24th. Thunderstorms were reported in the vicinity of Salalah from 15 GMT on the 25th to 00 GMT on the 26th, when hail was reported. The rainfall recorded at Salalah was very close to the 1943–71 average for October of 8 mm. Farther west, at Aden, the storm gave 150 mm of rain, whereas the annual average rainfall there is only 40 mm. In Djibouti 230 mm of rain fell (average annual rainfall 130 mm) and there was considerable disruption and loss of life.

Upper-air observations in the vicinity of the storm were almost completely absent, the nearest radiosonde ascent being at Masirah, and the nearest pilot-balloon ascent being at Salalah. In addition, however, there were some wind measurements by aircraft on the eastern flank of the storm on 20, 21, 25 and

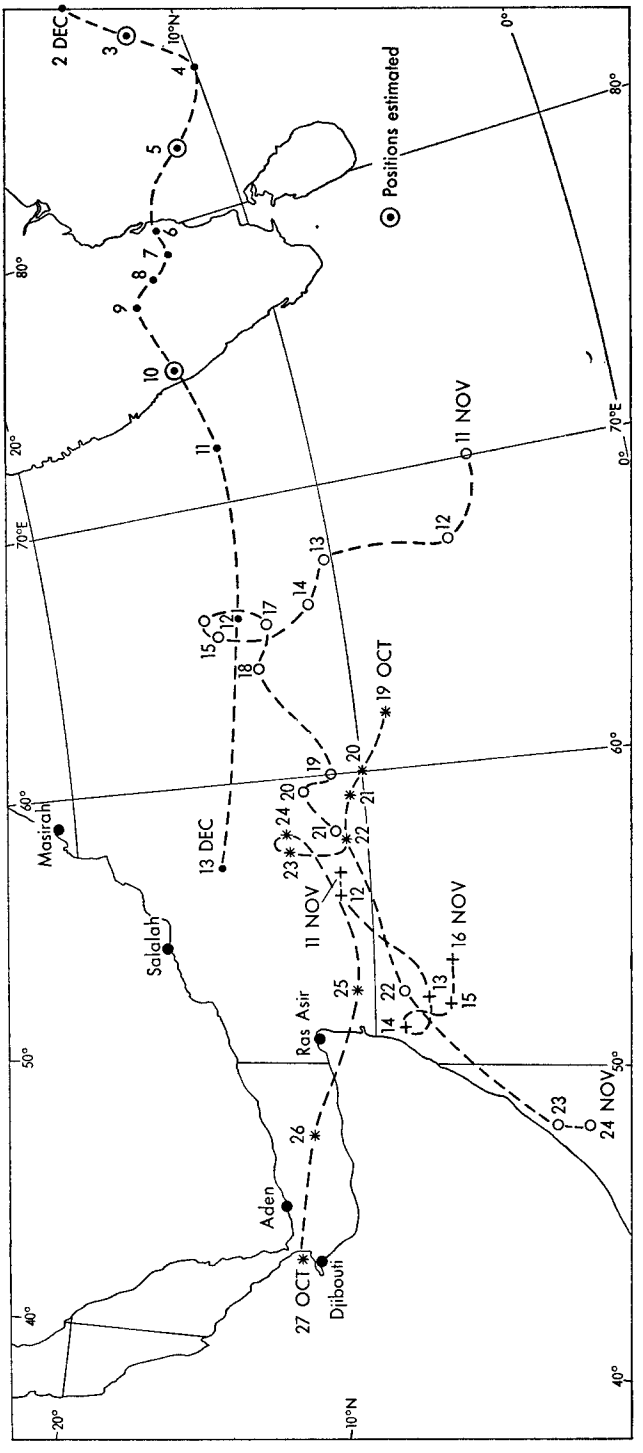

FIGURE 1—TRACKS OF FOUR TROPICAL STORMS OVER THE INDIAN OCEAN AREA—OCTOBER–DECEMBER 1972

26 October. Using this admittedly meagre amount of information it is possible to suggest a likely sequence of events at the 300-mb and 200-mb levels. On 19 and 20 October the storm moved slowly north-west and west as it emerged from the upper equatorial easterly flow. From the 21st to the 23rd a slow movement to the north and north-west continued around the western edge of the subtropical high. However, from the 22nd onwards 300-mb and 200-mb heights were rising over Arabia ahead of a marked upper trough extending southwards over the Red Sea. By the 23rd a considerable ridge had built up over Arabia, and by the 24th an anticyclonic circulation had developed over south-west Arabia. The easterly on the southern side of the upper high cell steered the storm into the Gulf of Aden.

Other storms during October–December 1972. The tracks of the other three storms of the October–December 1972 season are shown in Figure 1. These also were obtained from the daily ESSA 8 pictures only. The movements are often erratic and complicated, whilst the development and decay are very difficult to predict. It must be remembered that surface and upper-air reports from ships or aircraft are often completely absent over the Arabian Sea.

Conclusion. In this paper only four storms have been considered and the sample is too small to form the basis of any reliable forecasting rules regarding their movement and development over the Arabian Sea. However, it is possible to say that, in the main, these storms conformed to the following conditions:

(a) Fast movement was usually associated with decay (two out of three storms).

(b) Slow movement usually indicated intensification (two out of three storms).

(c) Poleward movement indicated intensification (two out of three storms).

(d) Storms over land decayed.

The occurrence of these Arabian Sea storms during October–December 1972 highlighted the value of weather satellites for the early detection of tropical storms and for forecasting their subsequent movement and development in an area of very sparse meteorological data. Continued regular surveillance of the area by weather satellite is likely to show an increase in the average previously reported frequency of occurrence of tropical storms over this particular sea area, but of more practical importance is the fact that meteorologists are now in a position to improve on the advice and warnings hitherto given over the Arabian Sea air routes and the adjacent coastal regions.

REFERENCES

1. PEDGLEY, D. E.; Cyclones along the Arabian coast. *Weather, London*, **24**, 1969, pp. 456–468.
2. London, Meteorological Office. The Somali Republic and French Somaliland. 1962. (Unpublished, copy available in the Meteorological Office Library, Bracknell, Berks.)
3. Washington, Environmental Science Services Administration, National Environmental Satellite Center. ESSA Direct Transmission System Users Guide, Washington, 1969.

551.553.6:629.7

OPTIMUM AVERAGING TIME OF WIND REPORTS FOR AVIATION

By M. J. O. DUTTON

Summary. For selected occasions during a 3-month winter period at London/Heathrow Airport, winds averaged over intervals of time from 30 seconds to 10 minutes were compared with the 30-second means at later times, simulating the procedure whereby wind observations provided by Air Traffic Control are used by a pilot; 30-second averaged winds logged by the digital anemograph logging equipment were used. The results are similar to those for an earlier study of summer situations at Heathrow: a 5–10-minute averaging period normally minimizes the root-mean-square error but the optimum periods for reducing errors exceeding various thresholds differ somewhat for threshold values of 12 knots or more; in general, the higher the threshold the shorter the averaging period necessary to minimize the frequency of departures exceeding that threshold. The few very large errors can be reduced by using a 30-second average at the expense of many more errors in the 6–14-knot range.

Introduction. The supply to aircraft pilots of a representative surface wind for take-off and particularly landing is an important feature in the safety of aircraft operations. This wind report is usually supplied to the pilot a few minutes before touchdown or take-off and in 1967 the International Civil Aviation Organization[1] (ICAO) provisionally recommended that a 2-minute average wind should be used until it had been shown to be inferior to a wind averaged over a different period. Sparks and Keddie[2] later showed that in a particular synoptic situation with strong westerly winds in a warm sector a 4–5-minute averaging period proved best for minimizing the root-mean-square (r.m.s.) differences between forecast and encountered winds. In a more recent study of turbulent occasions in a variety of synoptic situations during the summer of 1973 at London/Heathrow Airport, Hardy[3] clearly illustrated the apparent dependence of the optimum averaging period on the relative importance of departures or errors of different magnitudes. His results showed that the few very large errors can be reduced by using a 30-second average (at the expense of more errors in the lower ranges) and that the r.m.s. error can normally be minimized by using a 5–6-minute averaging period; he concluded that a 2-minute average appeared to be a satisfactory compromise, but stressed that his results applied to summer in southern England and that the results for winter might differ. ICAO[4] have since confirmed their recommendation of the use of a 2-minute average.

This note presents the results of an experiment designed to extend Hardy's work to winter-time at Heathrow, making use of winds logged by the digital anemograph logging equipment (DALE) operating in conjunction with a Meteorological Office Mk 5 wind system.[5]

Data for analysis. The DALE system, installed at Heathrow during December 1973, provided all the necessary data in the form of 30-second wind averages; it is a compact system with low power consumption which computes and records 30-second means of wind speed (to 0·1 knot), wind direction (to 1 degree), and maximum hourly gusts (speed to 1 knot, direction to 10 degrees). Wind speed is averaged instrumentally by electrical filter circuits before conversion to digital form; direction is converted to digital form at a 1-Hz sample rate before filtering.[6] The system is constructed in such a way that the time constant can easily be changed to enable a different averaging period to be used. DALE writes recorded data in 1-hour blocks on tape in a cassette together with the time and maximum-gust information for that hour.

The cassettes are changed about once a month and the data transcribed on to magnetic tape. Initially the data contained many errors (mainly missing or invalid characters) but most of the problems in the initial trial period were quickly eliminated, although interruptions to the mains supply were a continual source of annoyance; to combat this problem the equipment was brought up to full operational standard with the inclusion of a stand-by battery in April 1974.

After necessary quality control the wind data covering the period 20 December 1973 to 25 March 1974 (total of 1775 hours with a few short gaps in the record) were processed by computer to produce various relevant wind statistics. Subjective examination of these statistics proved useful in selecting for analysis a total of 287 hours of 'turbulent' occasions. Initially the occasions selected included all periods with 10-minute mean wind speed greater than 15 knots, rapid changes of wind speed or direction or both, or reports of heavy showers or cumulonimbus clouds (total of 362 hours). In the final selection of the periods for analysis (47 periods totalling 287 hours) one of the main objects was to include all occasions when vector changes in the 30-second wind over periods of up to 20 minutes exceeded 10 knots. (In fact about 95 per cent of such occasions were included since, as already mentioned, there were several short gaps in the DALE data and two or three important periods were not logged.) Of the 287-hour sample, 81 per cent was selected from the January and February 1974 records alone; except for the last week or so of February this period was abnormally windy and mild in the United Kingdom.

Analysis. The object of the investigation was to compare, on a large number of occasions, the wind which might be supplied to the pilot with the wind which he would actually have encountered some minutes later at touchdown or take-off. The departure or error is defined as the magnitude of the vector difference between the forecast wind (reported wind assuming persistence) and the actual or encountered wind, the wind affecting the aircraft at or near touchdown or take-off. The forecast or reported wind was taken as the observed wind averaged over a period of time varying from 30 seconds to 10 minutes (simple arithmetic averaging of the 30-second winds was used) and the actual wind was taken as the 30-second wind average some time (lag) later; this lag, which represents the interval between the wind observation and the aircraft touchdown or take-off, was also varied from 30 seconds to 10 minutes. As Hardy pointed out, the 30-second run of wind past a stationary anemometer will usually be equivalent to the distance covered by an aircraft in a few seconds of flight and therefore represents eddy sizes of the correct order.

For all 47 sample periods totalling 287 hours the errors at every time-step, for 20 averaging periods and 20 lags, were evaluated and various statistics of these errors were computed; 916 minutes of data were lost in computing initial means and final lags so that in fact 271 hours and 43 minutes of 30-second wind data were used.

Results

Root-mean-square errors. Figure 1 shows the variation of r.m.s. error as a function of averaging period for various lags from 30 seconds to 10 minutes. The pecked lines join points on each curve corresponding to r.m.s. errors 1 per cent greater than the minimum value for each curve and indicate that,

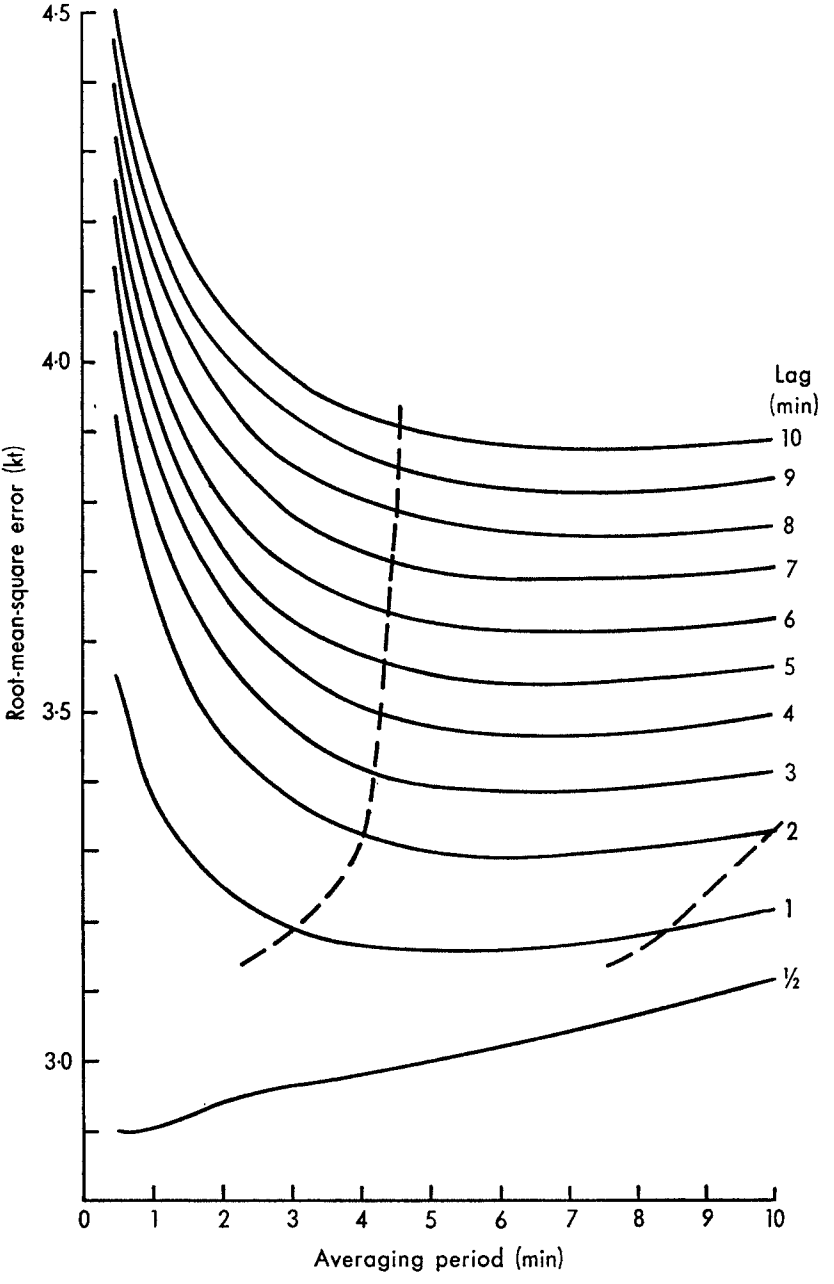

FIGURE 1—VARIATION OF ROOT-MEAN-SQUARE ERRORS WITH LAG AND AVERAGING PERIOD

The pecked lines join points on each curve corresponding to r.m.s. errors 1 per cent greater than the minimum value for each curve.

for a lag of 2 minutes or more, there is little to choose between averaging periods in the broad range of 5 to 10 minutes. It is obvious that for this range of averaging periods the r.m.s. error is much more sensitive to changes in lag than to changes in averaging period; for instance, a change in the latter from 7 minutes to 10 minutes at a lag of 5 minutes results in only a 0·6 per cent increase in r.m.s. error, whereas a change from a 5-minute to a 10-minute lag for a 7-minute averaging period produces a 9·3 per cent increase. For the shortest lag of ½ minute, a ½–1-minute average is best.

Percentages of errors exceeding various thresholds. Figures 2, 3 and 4 show the variation with averaging period, for various lags, of percentages of errors (out of a total of 32 607) exceeding 6 knots, 10 knots and 14 knots respectively.

(a) 6-*knot threshold* (Figure 2). For all lags greater than ½ minute the percentage of errors ⩾ 6 knots is a maximum for the shortest averaging periods and can be minimized by using an averaging period of 5 to 10 minutes; for a ½-minute lag a ½–1-minute average is best. For lags of 2 minutes or more the number of errors ⩾ 6 knots for a 2-minute averaging period (as recommended by ICAO) is 25–30 per cent greater than the number for a 5–10-minute averaging period.

(b) 10-*knot threshold* (Figure 3). For lags greater than 3 to 4 minutes the variation with averaging period of the percentage of errors exceeding 10 knots is similar to that for the 6-knot threshold; for the shorter lags Figure 3 shows that the optimum averaging period decreases from about 5 minutes for a 3-minute lag to 1 minute for a ½-minute lag. For lags of 3 minutes or more the number of errors exceeding 10 knots for a 2-minute averaging period is 22–27 per cent greater than the number resulting from the use of a 5–10-minute average.

(c) 14-*knot threshold* (Figure 4). Here the optimum averaging period appears to be about 3 to 6 minutes for lags of 5 minutes or longer and 1 to 2 minutes for the shorter lags.

(d) *Higher thresholds.* The results for higher thresholds show that the higher the threshold the shorter the averaging period necessary to reduce the number of errors exceeding that threshold.

Table 1 lists percentage frequencies of errors exceeding thresholds of 6 knots, 10 knots, 14 knots and 20 knots for 2-minute and 5-minute averaging periods and lags of 2, 5 and 10 minutes. The table illustrates well the sensitivity of

TABLE 1—PERCENTAGE FREQUENCIES OF ERRORS EXCEEDING VARIOUS THRESHOLDS

Lag	Threshold (kt)			
	6	10	14	20
minutes		*per cent*		
2-minute averaging period				
2	6.56	0·442	0·086	0·019
5	8·19	0·804	0·196	0·049
	(1·25)	(1·82)	(2·28)	(2·58)
10	10·98	1·227	0·319	0·104
	(1·67)	(2·78)	(3·71)	(5·47)
5-minute averaging period				
2	5·12	0·405	0·095	0·028
5	6·62	0·699	0·193	0·058
	(1·29)	(1·73)	(2·03)	(2·07)
10	9·36	1·027	0·316	0·101
	(1·83)	(2·53)	(3·32)	(3·60)

Figures in brackets are the percentages as proportions of the 2-minute lag values.

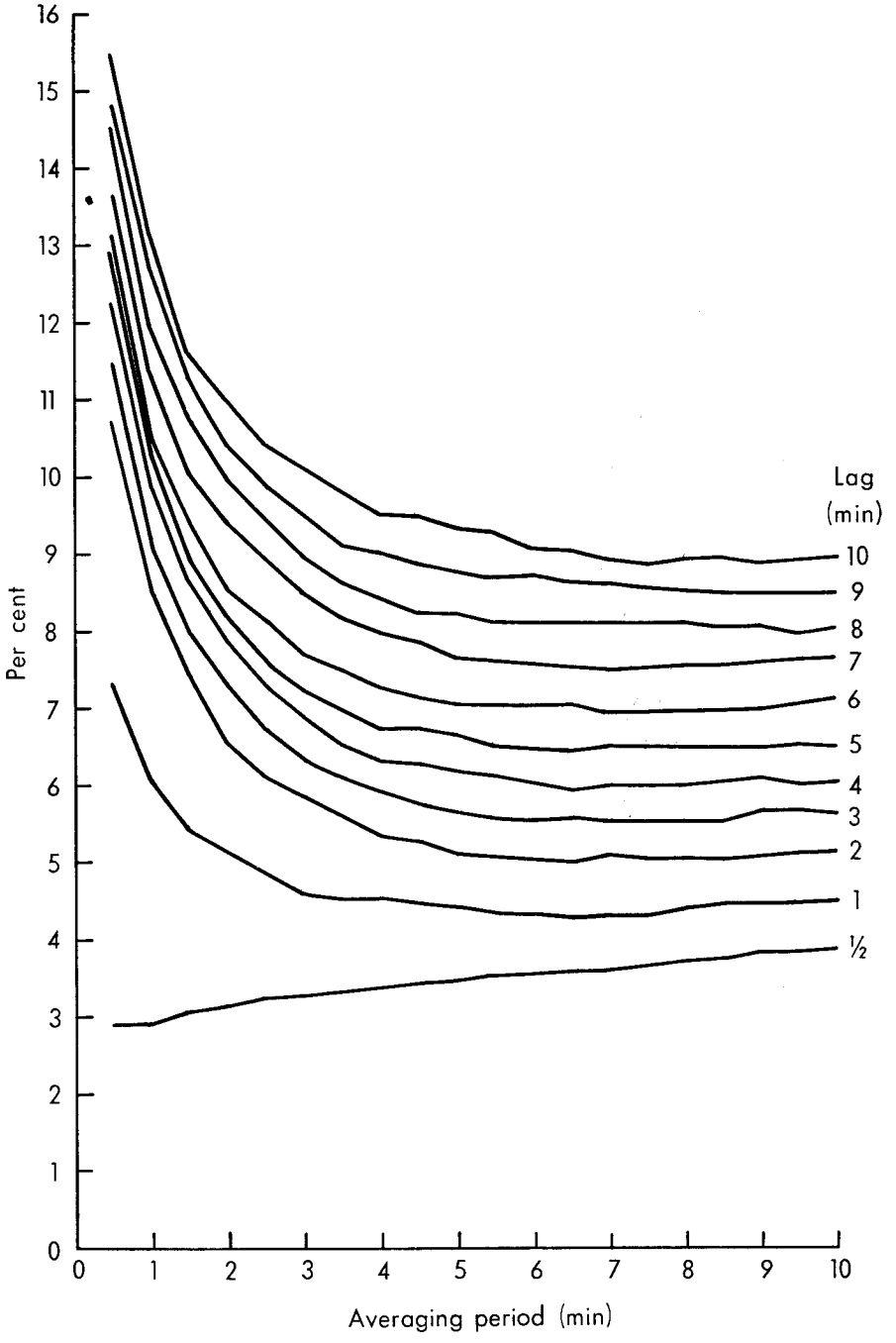

FIGURE 2—PERCENTAGES OF ERRORS $\geqslant$ 6 kt: VARIATION WITH LAG AND AVERAGING PERIOD

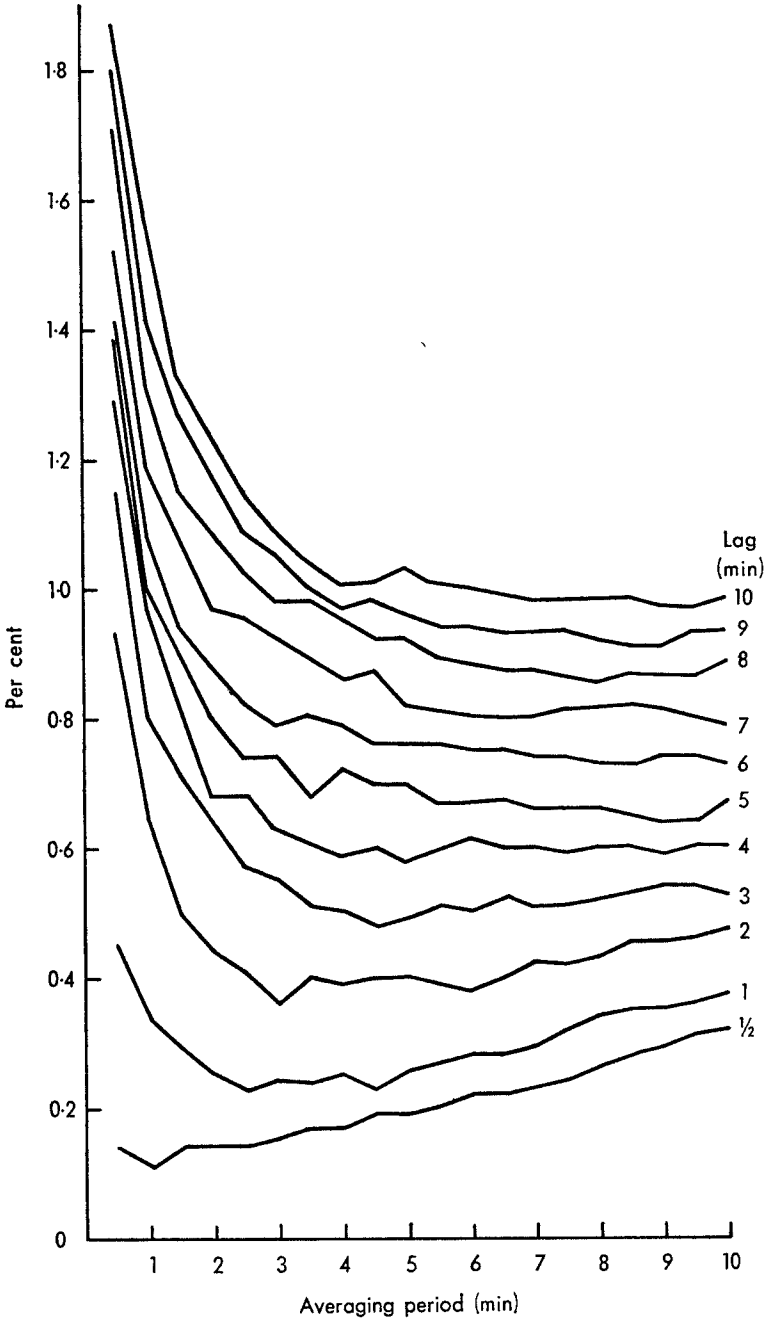

FIGURE 3—PERCENTAGES OF ERRORS ⩾10 kt: VARIATION WITH LAG AND AVERAGING PERIOD

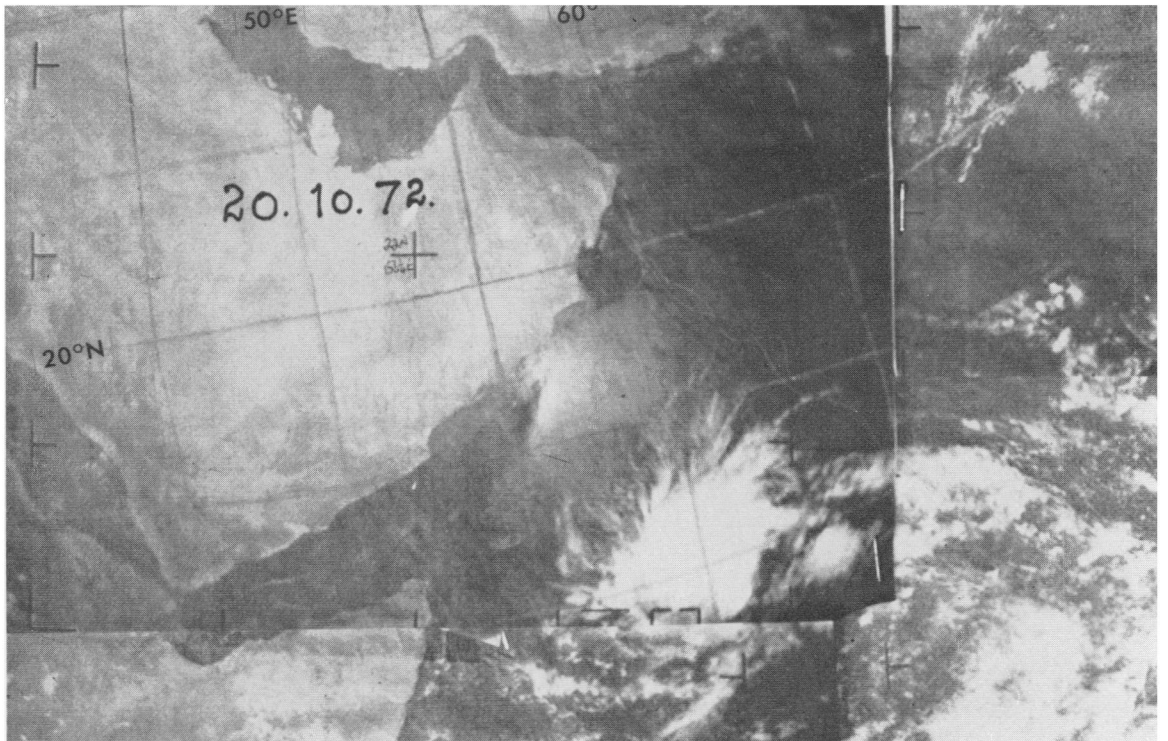

PLATE I—ESSA 8 SATELLITE PICTURE AS RECEIVED BY AUTOMATIC PICTURE TRANSMISSION AT MASIRAH ON 20 OCTOBER 1972

To face page 236

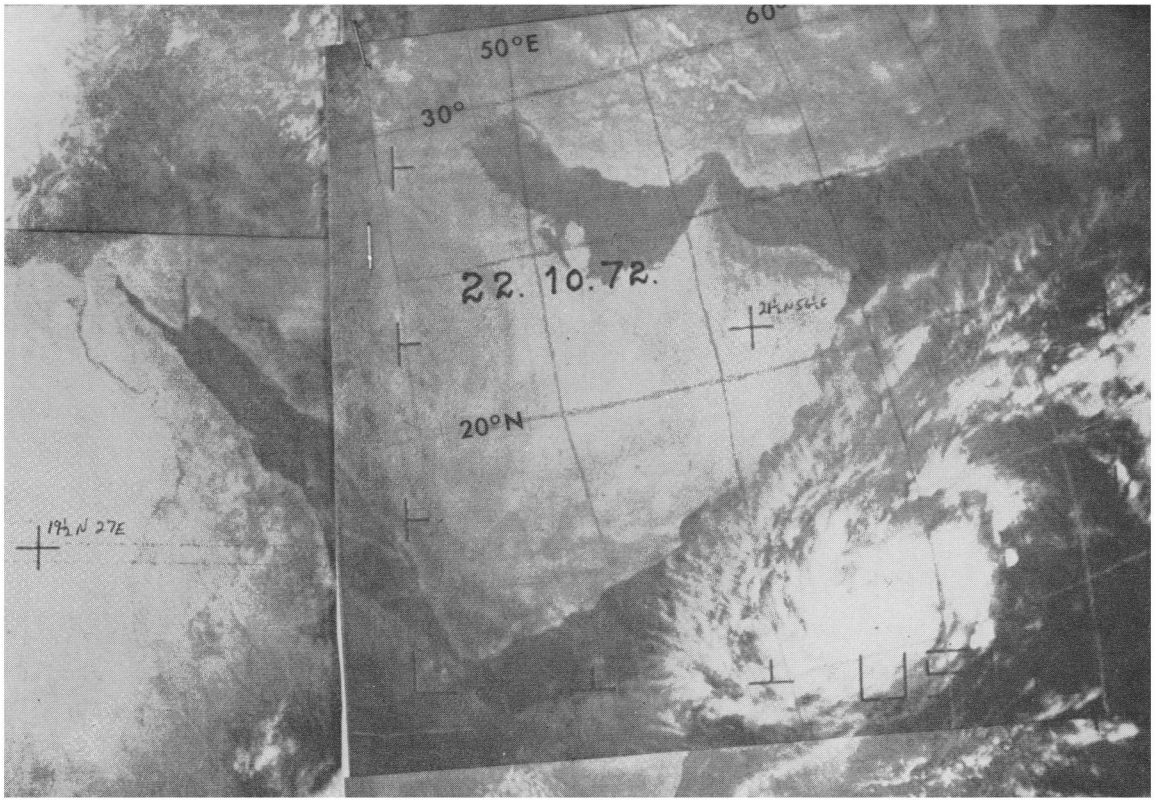

PLATE II—ESSA 8 SATELLITE PICTURE RECEIVED AT MASIRAH ON 22 OCTOBER 1972

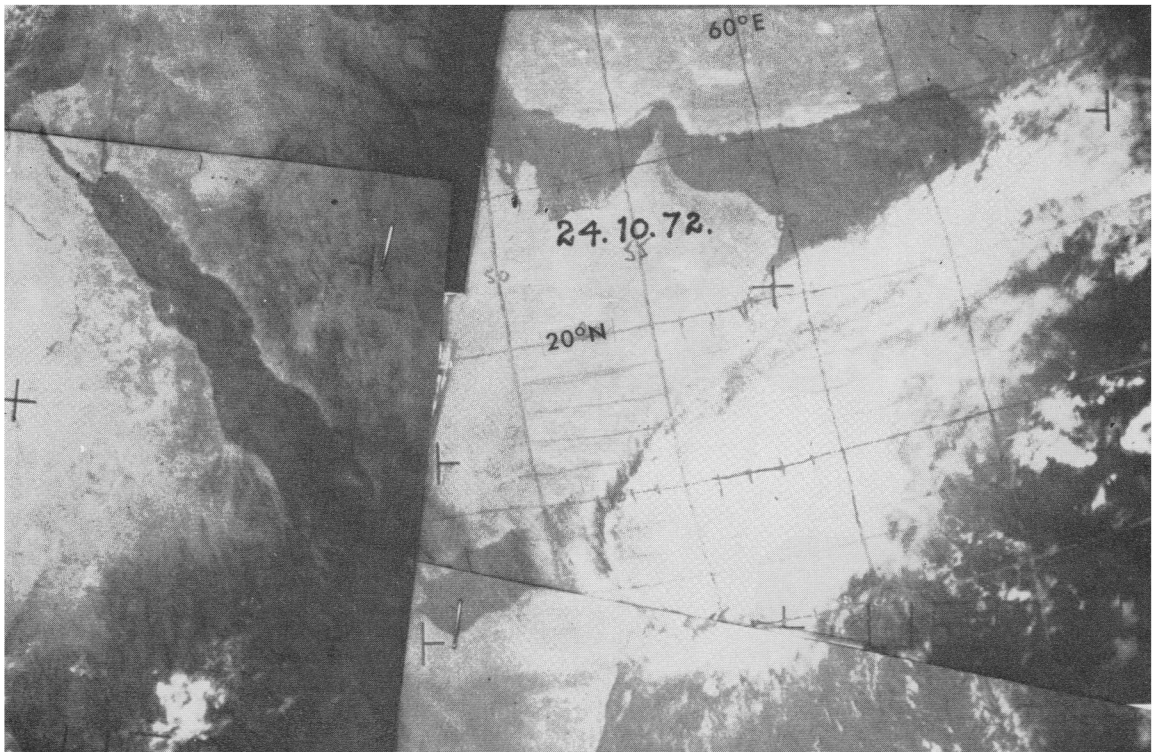

PLATE III—ESSA 8 SATELLITE PICTURE RECEIVED AT MASIRAH ON 24 OCTOBER 1972

To face page 237

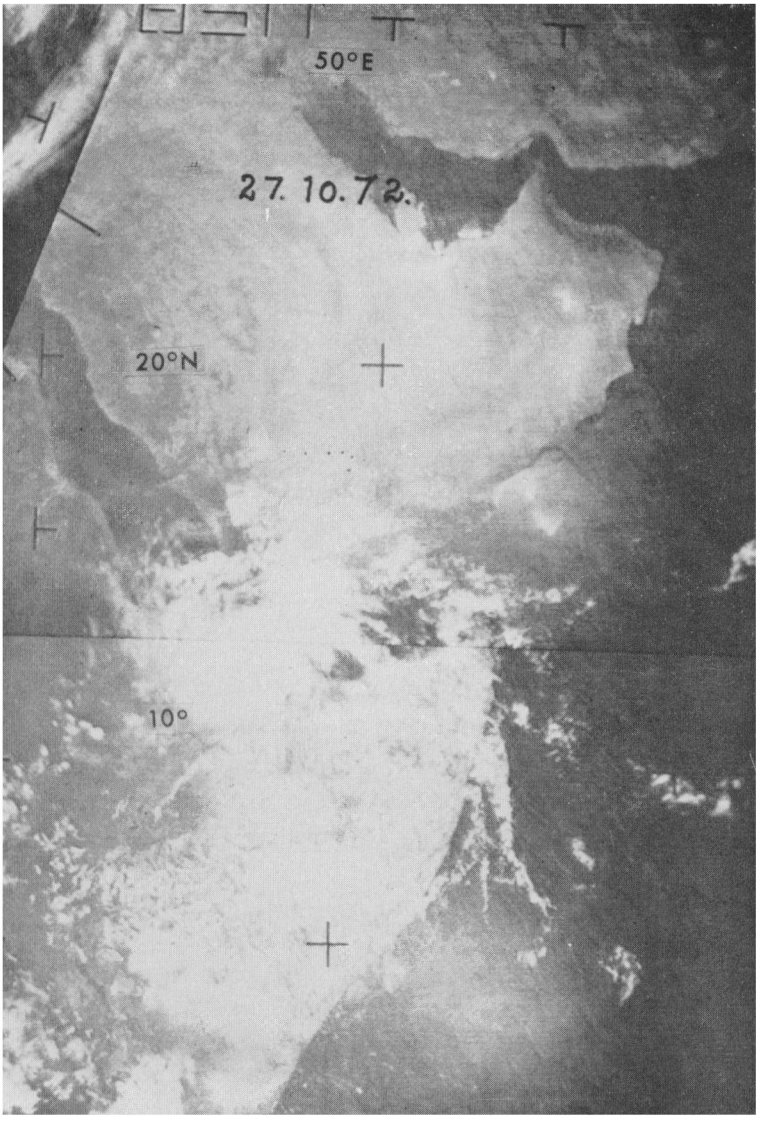

PLATE IV—ESSA 8 SATELLITE PICTURE RECEIVED AT MASIRAH ON 27 OCTOBER 1972

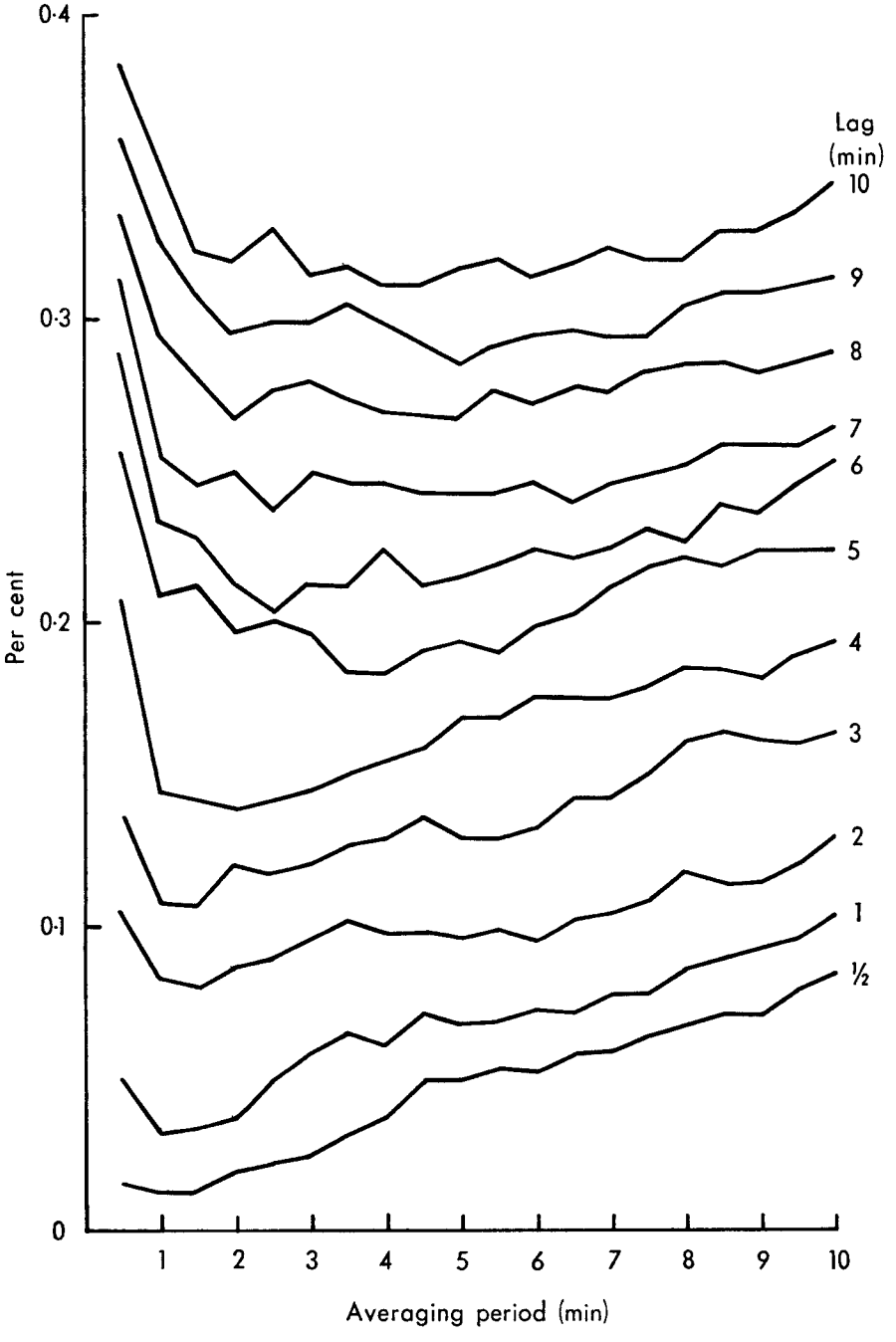

FIGURE 4—PERCENTAGES OF ERRORS ⩾ 14kt: VARIATION WITH LAG AND AVERAGING PERIOD

the figures to variations in lag and the increasing importance of as short a lag as possible as higher thresholds are considered. More than twice as many departures in excess of 14 knots occur with the use of a 5-minute lag as with a 2-minute lag for both averaging periods; if the lag is further increased to 10 minutes the frequency of these errors is over three times that for a 2-minute lag. At the 20-knot threshold the deterioration with lag is even more pronounced.

Discussion of results. The main difference between Hardy's summer results and those derived from this winter sample is that while the former suggested that, for all except the very short lags, errors exceeding 10 knots could be minimized by using a 1½–4-minute averaging period, the equivalent figures for winter show that a 5–10-minute average is best for lags of more than 3 to 4 minutes. In winter this averaging period also minimizes the r.m.s. error for lags greater than 1 minute; for summer, Hardy showed that a 5–6-minute average was best for minimizing the r.m.s. error.

The apparent discrepancy in the results for departures exceeding 10 knots is almost certainly due to the higher proportion, in the summer sample, of cases incorporating large and rapid wind-speed and direction changes. In a study of such 'events' at Bedford over a period of 4 years, Burnham and Colmer[7] showed that they were normally associated with convective activity and occurred mainly in spring and late summer; on average only about 12 per cent occurred in the 4-month period November–February while more than half occurred in the 3-month period March–May. The winter sample was in contrast dominated by a high proportion of cases approximating to steady state in which the wind speed was generally high (with roughly constant direction) producing a high level of turbulence; there were relatively few cases where there was a large and rapid shift of wind direction and when these did occur, usually in association with the passage of active cold fronts or thunderstorms, they were accompanied by quite large increases in wind speed. Figure 5 includes four such typical cases; they are in fact the four occasions which produced the largest vector wind changes over 10 minutes or less in the winter sample. Most of the very large departures occur in non-stationary situations such as these and it is obvious that a short averaging period and, what is more important, a short lag are both desirable if their frequency of occurrence is to be reduced. On the other hand, in strong-wind steady-state conditions when fluctuations of the 30-second wind about a relatively stable long-period mean can be large, a longer averaging period is usually superior.

It is interesting to note that the variation with averaging period and lag of the percentage frequencies of errors exceeding 14 knots in the winter sample (Figure 4) is similar to that for the percentage frequencies of errors exceeding 10 knots in the summer sample. For minimizing errors below these thresholds (10 knots in summer, 14 knots in winter) it appears that a 5-minute or longer averaging period is superior to a shorter-period average, especially for lags of 2 minutes or more, whereas for minimizing errors exceeding the thresholds a 1½–4-minute average is best.

The results of this winter analysis indicate that the true overall occurrence frequency of departures in excess of 10 knots is about 0·1 per cent or 1 in 1000 for a 5-minute lag and 5–10-minute averaging period (about 1 in 800 for a 2-minute average). It should be remembered, however, that errors of this

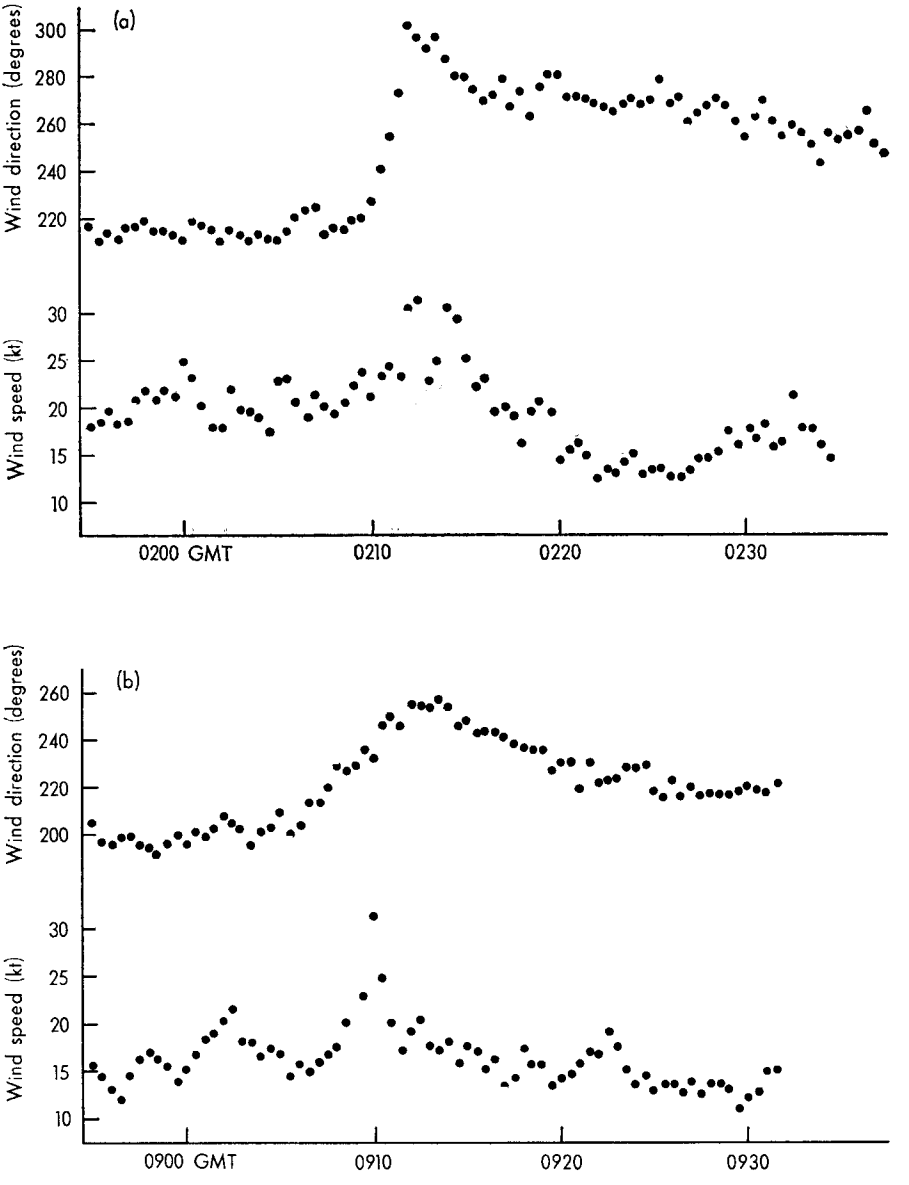

FIGURE 5—EXAMPLES OF LARGE, RAPID WIND CHANGES
(a) 11 January 1974 (b) 13 January 1974

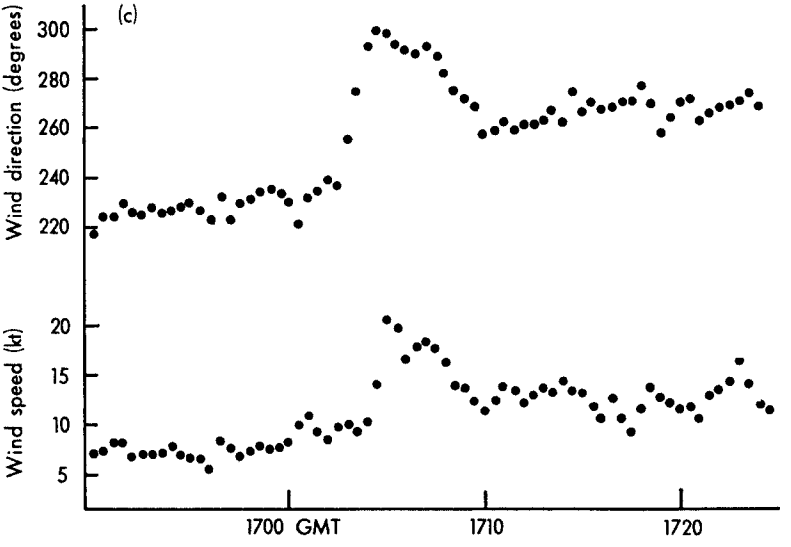

FIGURE 5—*continued*

(c) 2 February 1974 (d) 9 February 1974

magnitude and larger tend to occur in batches (i.e. occurrences are not entirely independent) and this tendency becomes increasingly pronounced as higher thresholds are considered.

This investigation and Hardy's study of summer situations has dealt only with the magnitude of the total vector departure and the question arises whether or not the results would be different for orthogonal components of the vector departure. The most obvious components to consider are those along (longitudinal) and across (lateral) the runway direction. The longitudinal component is usually more critical than the lateral component during landing and take-off.

Figure 6 shows some results of a limited pilot analysis (using two relatively small contrasting samples, for a 5-minute lag only) in which the total vector error was split into orthogonal components along and across the reported (forecast) wind direction. These components were chosen for the pilot study simply because the required data are contained in the winds themselves whereas an analysis of error components along and across the runway direction requires a knowledge of runway usage during the appropriate periods; there is no simple relationship between wind direction and runway selection at Heathrow.

The sample in case 1 is a single continuous 23-hour period in which the conditions approximated to steady state for much of the time; case 2 comprises six different periods totalling 32 hours which contain numerous large and rapid changes of wind direction or speed or both in mainly non-stationary conditions. The pecked and dotted lines in the figure represent the variations with averaging period of the percentage frequencies of error components exceeding 10 knots (components are along and across the direction of the forecast wind). The most interesting feature is that the variation in the frequency of large longitudinal errors is similar in the two cases, the frequency steadily decreasing with increasing averaging period. The percentage frequencies of large lateral errors are small for all averaging periods in case 1, but are appreciably larger in case 2 (exceeding the along-wind figures for averaging periods of 2 minutes or more) and increase with averaging period. So, on the basis of these two samples, it seems that an averaging period of 5 to 10 minutes minimizes the frequency of longitudinal errors in excess of 10 knots in most situations, but a short averaging period (less than 2 minutes) is apparently required to minimize the frequency of large lateral errors. However, the samples are small and this aspect of the optimum-averaging-period problem may require further study.

In this study, simulation of the aircraft landing and take-off situation has been attempted, but the method of simulation used is not entirely adequate, since only temporal variations of the wind have been examined, the reported or forecast wind and the actual wind some time later being compared at the same point. In the real operational set-up, unless the anemometer site happens to be near the take-off or touchdown point, the actual wind is experienced at a point which may be far removed from the anemometer. If accurate simulation is to be achieved, the appropriate spatial as well as temporal wind changes should be considered. Even if it can be assumed that the wind variations at one point are sufficiently representative of the required two-point differences, and this is probably a reasonable assumption for 30-second averages over homogeneous terrain and for a limited separation of the two points,

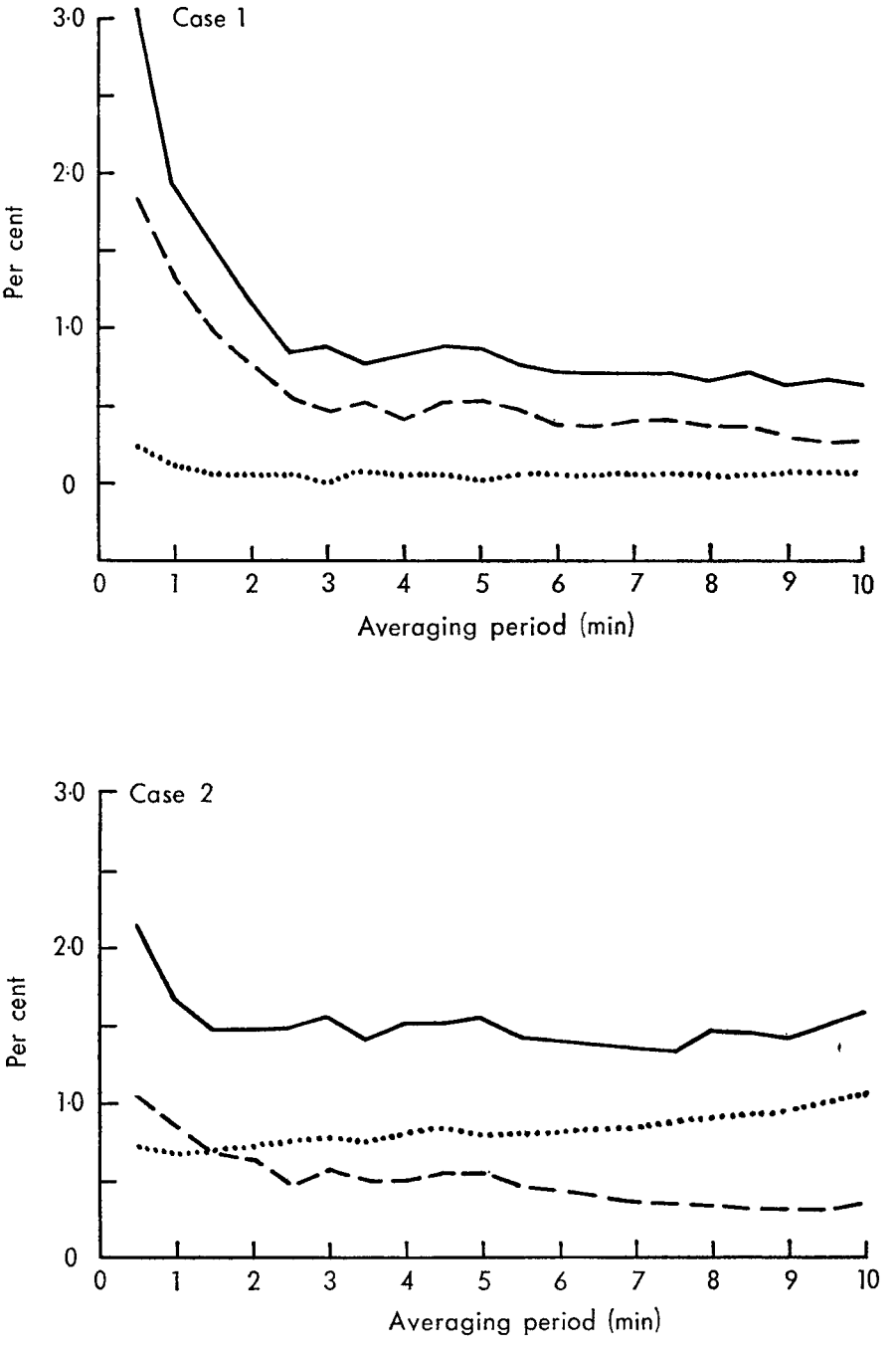

FIGURE 6—PERCENTAGES OF ERRORS ⩾ 10 kt: VARIATION WITH AVERAGING PERIOD FOR 5-MINUTE LAG

——— Total error – – – – Along-wind error component
. . . . . Across-wind error component

another important factor to bear in mind is that the effective lag is reduced if the anemometer is sited upwind of the touchdown point.

Summary of the main winter results. Analysis of 287 hours of winter 30-second wind records, logged by the DALE system at Heathrow, has shown that:

(a) Differences between the reported mean wind and the actual encountered wind some time later can be most significantly reduced if the time lag between the wind observation and touchdown or take-off is reduced to a minimum.

(b) A 5–10-minute averaging period minimizes the root-mean-square difference for all lags except the shortest ($\frac{1}{2}$-minute) when a $\frac{1}{2}$–1-minute average is best.

(c) For lags greater than 3 or 4 minutes a 5–10-minute average minimizes the number of departures exceeding 10 knots; for the shorter lags a 1–4-minute average is best. In general the higher the threshold and the shorter the lag, the shorter the averaging period necessary to minimize the frequency of departures exceeding that threshold.

(d) The ICAO-recommended 2-minute averaging period reduces the frequency of very large departures (greater than 15 knots or so), particularly for the shorter lags, but the resultant departures in excess of 10 knots are about 25 per cent more frequent than with a 5–10-minute averaging period if the lag is 3 minutes or more.

REFERENCES

1. Montreal, International Civil Aviation Organization. Report of the 5th Air Navigation Conference, Montreal. Doc 8720, AN-CONF/5, Montreal, 1967.
2. SPARKS, W. R. and KEDDIE, BARBARA; A note on the optimum averaging time of wind information for conventional aircraft landings. *Met Mag, London*, **100**, 1971, pp. 129–134.
3. HARDY, R. N.; A note on the optimum averaging time of wind reports for aviation. *Met Mag, London*, **103**, 1974, pp. 99–105.
4. Montreal, International Civil Aviation Organization. Report of the 8th Air Navigation Conference, Montreal. Doc 9101, AN-CONF/8, Montreal, 1974.
5. ELSE, C. V.; The Meteorological Office Mk 5 wind system. *Met Mag, London*, **103**, 1974, pp. 130–140.
6. PAINTING, D. J.; Digital averaging of wind direction (unpublished, copy available in the Meteorological Office, Operational Instrumentation Branch, Beaufort Park, Bracknell).
7. BURNHAM, J. and COLMER, M. J.; On large and rapid wind fluctuations when the wind had previously been relatively light. *RAE Tech Rep* 69261, *Farnborough*, 1969.

551.577.23 (414 + 422)

ANNUAL DURATION OF ANY RAINFALL INTENSITY

By M. C. JACKSON

Summary. Several sources of data are discussed and results of their analysis are combined to produce rainfall-intensity statistics suitable for London and similar parts of the south and east of England. A composite graph showing the average fraction of total time during which any rainfall intensity is exceeded is derived from these statistics. A curve derived from similar sources for Eskdalemuir, Dumfriesshire is shown for comparison. It is suggested that the type of information given by these composite curves can be obtained for other parts of the United Kingdom, and that maps could be drawn for various intensities of rainfall.

Introduction. Information on the total time per year during which specified rainfall intensities are likely to be equalled or exceeded has long been sought by engineers, rainfall-sensitive industries and, particularly in the last few years, engineers concerned with propagation of radio signals through the free atmosphere. Harrold[1] has reviewed the present position and discussed the potential use of weather radar to derive attenuation statistics for radio signal propagation. Statistical estimates of rainfall intensity at a point have been made by Briggs,[2] and Briggs and Harker,[3] who used the relationships with clock-hour rainfall totals. Recently further direct data have become available and these are used here in conjunction with data from other sources to produce estimates of the fraction of total time (i.e. fraction of the 'average' year) during which specified rainfall intensities are exceeded.

Analysing the data

Rainfall amount and duration tabulations. Hourly values of rainfall amount and duration at London/Heathrow Airport from the Dines tilting-siphon rain-gauge have been recorded on Meteorological Office Metform 3440 and are now stored on magnetic tape for virtually the whole of 23 years. Recently Hardy (private communication, 1974) has analysed these data to produce the total duration of rainfall between various values. From these data the average duration, expressed as a fraction of total time, can be estimated for rainfall intensities greater than (or equal to) any given value. However, tabulations on Metform 3440 are never made to a greater precision than 0·1 hour, so that the durations of short, rare events are inevitably underestimated.

For several stations in the United Kingdom the average annual duration of intensity greater than or equal to 0·1 millimetre per hour was compared with the 1941–50 average rainfall duration given in *British Rainfall* 1957,[4] and found to be quite similar, with approximately 450 hours per year for stations in the London region (a fraction of total time equal to 5×10^{-2}) but with large differences between individual station values. The data for Kew, 1956–71, derived directly from Metform 3440 gave durations which were more than 10 per cent greater than those given in *British Rainfall*. Such discrepancies may be expected for low rainfall intensities, bearing in mind the differences between the frictional characteristics of various rain-recorders, and are not considered further in this paper.

Rapid-response rain-gauge tabulations. Other sources of data were investigated, and data from one year's operation of the rapid-response rain-gauge at the Radio and Space Research Station (RSRS) at Slough as presented by Norbury *et alii*[5] were used to extend information for a wide range of rainfall intensities above about 3 mm/h occupying fractions of total time of less than 5×10^{-3} (about 40 hours per year). Results were very close to those obtained from tabulations on Metform 3440 from readings taken at London/Heathrow Airport which gave, for the same lower limit of intensity, a fraction near 5×10^{-3}, and very close to the results obtained by Evans (private communication, 1974) from the rapid-response rain-gauge at Colchester (University of Essex) for intensities occupying fractions of total time between 10^{-3} and 10^{-4}.

The RSRS equipment counts the average rainfall intensity over 10-second intervals through the year and records the clock time by a data-logging system with a paper-tape output, so that a count of total duration above any specified

intensity can be made. It is described more fully by Norbury and White.[6] Further data are being produced for subsequent years.

The use of only one year's data raised the question of their representativeness, especially for very short durations. Durations calculated from Jardi rate-of-rainfall tabulations for Kew between 1934 and 1943, for intensities equal to or greater than 10 mm/h, show that the coefficient of variation (the standard deviation divided by the mean) of annual durations is rather more than 10 per cent; this coefficient will become even greater at shorter durations (and higher intensities). However, the values from the rapid-response rain-gauge are probably the best estimates of the true mean values that are available for fractions between 10^{-3} and 10^{-5}.

Jardi rate-of-rainfall recorder tabulations. The Jardi rate-of-rainfall recorder[7] measures rainfall intensities instantaneously (in practice it has been estimated to average over 15-second intervals), and four or five such instruments have been in operation at different places in the United Kingdom. One of them was operating fairly continuously at Kew Observatory for many years, and tabulations for 10 years from 1934 to 1943 were analysed to obtain the fraction of total time with intensities greater than 10 mm/h. This fraction ($6{\cdot}8 \times 10^{-4}$) was found to agree quite closely with that from the rapid-response rain-gauge ($5{\cdot}3 \times 10^{-4}$) at an intensity of more than 10 mm/h.

It was found from Jardi tabulations that an intensity of more than 50 mm/h occurred on average 15·3 times per year on a total of 8·6 days (Table I). If this is combined with a fraction of total time (from the rapid-response rain-gauge for 1970) equal to $5{\cdot}3 \times 10^{-5}$ (or approximately 30 minutes per year), a rainfall event* of intensity more than 50 mm/h is suggested to last, on average, about 110 seconds. From this duration it is tentatively suggested that rainfall events of intensity greater than 75, 100 and 150 mm/h would have average durations of about 90, 75 and 50 seconds (i.e. reducing slowly with increasing intensity, but remaining of the same order of magnitude).

TABLE I — ESTIMATES FROM JARDI DATA, OF FRACTIONS OF TOTAL TIME DURING WHICH THE GIVEN RAINFALL INTENSITIES ARE EXCEEDED

Rainfall intensity exceeded *mm/h*	Days per year	Events per year	Average duration of event *s*	Fraction of total time
50	8·61	15·3	109	$5{\cdot}3 \times 10^{-5}$
75	3·70	(6·5)	(90)	$(1{\cdot}9 \times 10^{-5})$
100	1·65	(2·8)	(75)	$(6{\cdot}7 \times 10^{-6})$
150	0·26	(0·4)	(50)	$(6{\cdot}3 \times 10^{-7})$

Estimated values are in brackets.

The ratio of the number of days to the number of events with rainfall intensity more than 50 mm/h is 1·77. This value should stay fairly constant or reduce only very slowly with more intense rainfall events, and the value was used with the average annual number of days with intensities greater than 75, 100 and 150 mm/h to produce tentative estimates of the average number of events per year. The estimates of the average number of events per year (column 3 in Table I) and the average duration of the event (column 4 in Table I) help to make possible a tentative extension of the graph down to a fraction of total time

* 'Rainfall event' is here defined to mean a continuous period of rainfall with mean intensity greater than some specified value.

equal to 6×10^{-7} (approximately 20 seconds per year). It was encouraging that estimates of intensity for these very small fractional durations agreed well with those obtained directly from a very small quantity of data from the rapid-response rain-gauge.

The diagram. Results from the various data sources described in the previous section were plotted on one diagram (Figure 1). The range of intensities and durations is so large that log–log graph paper is essential. The final composite curve, shown as a full line in Figure 2, was obtained by inspection and subjective smoothing of the data, the higher-intensity values from London/Heathrow Airport and the lower-intensity values at the University of Essex being ignored, and represents London or somewhere with similar rainfall in south and east England. Table II presents some of the estimates derived from Figure 2 for specified rainfall intensities, both in fractional and actual durations.

TABLE II — ESTIMATES OF AVERAGE FRACTION OF TOTAL TIME DURING WHICH GIVEN RAINFALL INTENSITIES ARE EXCEEDED IN THE LONDON REGION

Rainfall intensity exceeded *mm/h*	Actual duration in an 'average' year	Fraction of total time
0·1	440 h	$5{\cdot}0 \times 10^{-2}$
0·5	320 h	$3{\cdot}7 \times 10^{-2}$
1·0	220 h	$2{\cdot}5 \times 10^{-2}$
4	28 h	$3{\cdot}2 \times 10^{-3}$
10	4 h 40 min	$5{\cdot}3 \times 10^{-4}$
25	1 h 15 min	$1{\cdot}4 \times 10^{-4}$
100	3½ min	$6{\cdot}7 \times 10^{-6}$

For contrast, a similar analysis for Eskdalemuir, Dumfriesshire (altitude 242 m, 1916–50 average annual rainfall 1580 mm, average annual duration of rainfall 1200 hours) was derived from autographic rainfall-recorder and Jardi rate-of-rainfall recorder tabulations, and added to Figure 2 (dashed curve). The average annual rainfall and the average duration of all rainfall at Eskdalemuir are both about two-and-a-half times typical values for south-east England.

Discussion. The parts of the composite curves in which the author is most confident are those between fractions of the year of 10^{-2} and 10^{-4}. At low rainfall intensities more elaborate equipment is needed to indicate when the intensities go below or above a certain value. For the high-intensity–short-duration part of the diagram, where there is most interest, many more data are needed, covering several years, from equipment which can accurately record all 'cloudburst' rain.

Similar curves for other parts of the country would be obtained if relationships were to be derived between rainfall parameters as described in this paper and rainfall parameters for rare rainfall events such as those given in the Flood Studies Report.[8] The extension of the work is possible since rainfall tabulations are available for analysis from some 25 stations in the United Kingdom, and the Flood Studies Report contains methods of obtaining detailed mapping of relevant rainfall parameters for uncommon events.

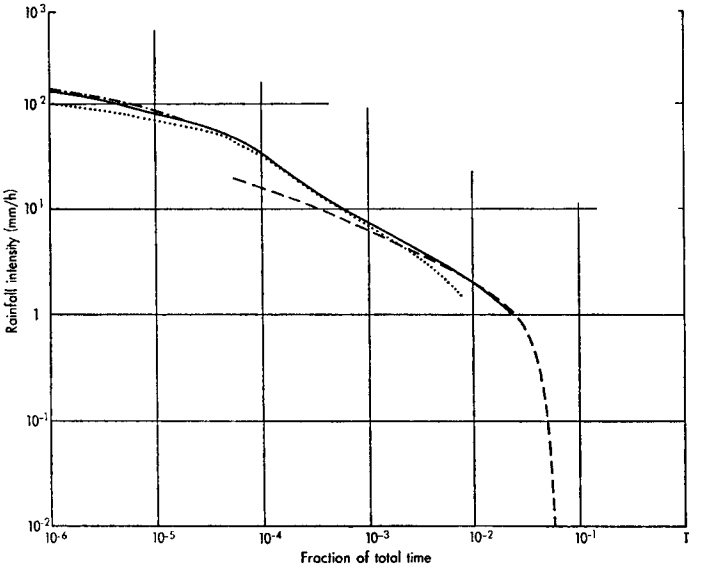

FIGURE 1—FRACTION OF TOTAL TIME IN WHICH SPECIFIED RAINFALL INTENSITIES ARE EXCEEDED

——— Rapid-response rain-gauge at Slough
. . . . . Rapid-response rain-gauge at Colchester
— — — Hourly rainfall tabulations at London/Heathrow Airport
—·—·— Jardi rate-of-rainfall recorder at Kew

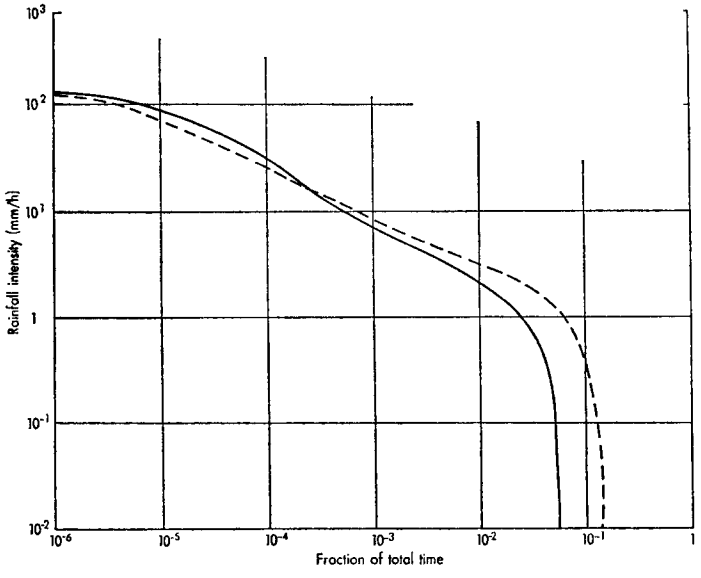

FIGURE 2—FRACTION OF TOTAL TIME IN WHICH SPECIFIED RAINFALL INTENSITIES ARE EXCEEDED

——— Derived from data sources in Figure 1 for the London region
— — — Curve for Eskdalemuir, Dumfriesshire, shown for comparison

Conclusion. Figure 2 was drawn from tabulations of rainfall amounts and durations at London/Heathrow Airport, direct counts by rapid-response raingauges at the Radio and Space Research Station at Slough and at the University of Essex at Colchester, and tabulations from the Jardi rate-of-rainfall recorder at Kew. With these data the composite curve of fraction of total time against intensity was extended down to fractions of total time equal to 10^{-6}. A curve derived in a similar manner for Eskdalemuir in the southern uplands of Scotland is added to show the contrast for a significantly rainier place. Until new and more plentiful observations become available, the main composite curve in Figure 2 should be of use to the many inquirers for estimates of this kind, especially in south and east England, and could lead to the production of estimates for other parts of the United Kingdom.

REFERENCES

1. HARROLD, T. W.; The use of weather-radar data in communication engineering. *Met Mag, London*, **103**, 1974, pp. 125–129.
2. BRIGGS, J.; Estimating the duration of high-intensity rainfall. *Met Mag, London*, **97**, 1968, pp. 289–293.
3. BRIGGS, J. and HARKER, J. A.; Estimates of the duration of short-period rainfall rates based on clock-hour values. *Met Mag, London*, **98**, 1969, pp. 246–252.
4. London, Meteorological Office. British Rainfall 1957. London, HMSO, 1960, pp. 33–34.
5. NORBURY, J. R., WHITE, W. J. K. and HARDEN, B. N.; Rainfall records at the Radio and Space Research Station Slough, 1970. Slough, Radio and Space Research Station, 1971.
6. NORBURY, J. R. and WHITE, W. J. K.; A rapid response raingauge. *J Phys*, E, *Scient Instrum*, **4**, 1971, pp. 601–602.
7. London, Meteorological Office. Handbook of meteorological instruments, Part I. London, HMSO, 1956, pp. 280–282.
8. London, Natural Environment Research Council. Flood Studies Report, Vol. 2, Meteorological studies. London, NERC, 1975.

REVIEW

New Science in the solar system, edited by P. Stubbs. 300 mm × 210 mm, pp. 65, *illus.*, New Science Publications, 128 Long Acre, London WC2E 9QH, 1975. Price: £1.

This little book (or large pamphlet) contains 13 articles which together give a fairly comprehensive account, in quite simple terms, of current knowledge of and ideas about the planets. The contents comprise: 'Cosmogony Now' (John Darius), 'The Sun from Skylab' (John Eddy), 'Mercury' (John Guest), 'Venus' (Garry Hunt), 'Earth' (Peter Stubbs), 'Moon' (Thomas Gold), 'Mars' (Harold Masursky), 'Weather on the Inner Planets' (Richard Goody), 'Jupiter' (Garry Hunt), 'Saturn and Beyond' (Simon Mitton), 'The Debris' (Keith Hindley), 'Future Missions' (Garry Hunt) and 'Exobiology' (Carl Sagan). It can be seen that the contributions carry authority, although occasionally carried away by enthusiasm in such extravagant phrases as 'a milestone in space exploration, and more than an epoch in solar physics'. The casual reader will immediately be impressed by the range and quality of the photographs and diagrams, for the most part drawn from NASA material. Many people will find it worth while to

have this book for its varied and valuable photographs and diagrams alone. I have one main criticism. The value of the book is seriously, indeed damagingly reduced, by the absence of references. I find this inexcusable. A few key references, such as the account of the MARINER 10 and PIONEER 10 results in *Science*, of the lunar seismic results, of the Moon's gravity field, of plate tectonics, and so on—just one or two items in each article, would have made the book an excellent starting point for studying recent work more thoroughly; as it is, its value to the serious student is very little. A minor criticism is that the proofs have been carelessly read—there are a number of annoying and rather trivial misprints.

This is no place, nor is it the time, to write a comprehensive review of our knowledge of the solar system. 'The Solar System' does however call to one's attention the number of illuminating comparisons that it is now possible to make between various bodies in the solar system.

We know the size, mass and density of all planets and most satellites; for most, with the principal exception of Pluto, the uncertainties are relatively low. We know the moments of inertia for many (Mercury, Venus and Pluto are the principal exceptions) and so we have an idea of central condensation of mass and the likelihood of a core. The Moon must have a nearly uniform density, about the same as the mantle of the Earth, Mars is little condensed, Jupiter and Saturn very strongly condensed. In view of the relatively high mean densities of Mercury and Venus it is unfortunate that we have no indication from the moments of inertia as to how much the density may increase with depth. We have seismic information only about the Moon, but the picture is intriguingly different from that of the Earth. We know that the rate of heat flow per unit area from the Moon is about half that from the Earth; we also know that heat flows out of Jupiter. The Earth and Jupiter have strong magnetic fields; Mercury has an appreciable one, while the Moon, Mars and Venus have very small fields, probably of complex structure. The Earth, Venus, Jupiter and the satellite Io have atmospheres with ionospheres controlled by the height of maximum absorption of solar radiation; the Earth, Jupiter and Mercury have magnetospheres in equilibrium between the magnetic field of the planet and the field convected by the solar wind. Finally, the appearances of the surfaces of the Moon, Mars and Mercury, being unshielded by atmospheres, are dominated by craters formed by impacts of meteorites, while the Earth, the Moon, Mars and Mercury all appear to be asymmetrical, two hemispheres of different appearance being distinguishable. Such comparisons are stimulating alike to theory and to observation; one virtue of 'The Solar System' is that it calls them to our attention.

A. H. COOK

LETTER TO THE EDITOR

551.509.334:551.583.1

Reflections upon some unusual years

An article[1] in the *Meteorological Magazine* for March 1975, referring to some of my earlier work on the rainfall of the British Isles, prompts me to make the following comments.

On page 66 the authors state that monthly values for England and Wales were published in the *Meteorological Magazine* for 1928, but this article gave only the annual values, the monthly values being published later.[2] The uncertainty of the values for the earlier years was explained in both these articles.

One reason for this work was that I had noted some necessary revisions to the earlier published annual values by Symons. This revision involved much preliminary work, including the preparation of annual[3] and decadal[4] maps. I had always hoped that before retiring it would have been possible for me to go over this work using the 'ancient records' which were being accumulated by the Meteorological Office. In the further examination of these earlier records, which now seems overdue, I hope that this cartographical approach will be combined with statistical analysis.

On pages 66 and 67 the authors do not mention that the rainfall distribution over the country has been defined and published for many years, including the wet 1872 and the dry 1887.[3]

On page 68 the authors conclude that since 1727 both 1768 and 1852 rival 1872 in being very wet over a large part of the country. This is not a new idea since in the 1928 article on 'Two centuries of rain' there is a similar statement that 'the three years 1768, 1852 and 1872 were markedly wetter than 1927'.

On page 62 the authors compare Lamb's Daily Weather Types with the annual rainfall in extreme years. It may be worth recording that earlier[5] a comparison was made for each of the years 1868–1921 of the rainfall in the west, east, south and north of the country with the annual pressure and the pressure gradients south–north and west–east. This paper gives some interesting results which might warrant further study.

On page 65 the authors state that in the discussion of Reynolds's paper no mention was made of the unique position of Bidston in the rain-shadow of Snowdonia. This is fully explained in the first page of Reynolds's paper and those who discussed the paper realized that this could not account for the wetness of 1872 there. In the first place, percentages of annual averages are locally almost independent of the orography; then the percentage map for 1872 showed seven other areas, well distributed over the country from the east coast to the Cheshire Plain with 170 per cent of average, as recorded in the Bidston area. Clearly the similar rainfall of all these eight areas could not be due to similar rain-shadow effects.

87 *Mostyn Road*
*London SW*19 3*LW*

J. GLASSPOOLE

REFERENCES

1. CRADDOCK, J. M. and WELLER, M. J.; Reflections on some unusual years. *Met Mag, London*, **104**, 1975, pp. 61–69.
2. NICHOLAS, FRIEDA J. and GLASSPOOLE, J.; General monthly rainfall over England and Wales 1727 to 1931. *Brit Rainf* 1931, *London*, 1932, pp. 299–306.
3. London, Royal Meteorological Society. Rainfall atlas of the British Isles. London, 1926, pp. 4–31.
4. GLASSPOOLE, J.; The rainfall over the British Isles of each of the eleven decades during the period 1820 to 1929. *Q J R Met Soc, London*, **59**, 1933, pp. 253–258.
5. SALTER, C. and GLASSPOOLE, J.; Fluctuations of annual rainfall over the British Isles considered cartographically. *Q J R Met Soc, London*, **49**, 1923, pp. 207–225.

Reply by Mr J. M. Craddock:

The main purpose of our paper is to find better arguments for answering questions such as 'What is the statistical probability of another year as wet as, or wetter than, 1872?' I am glad Dr Glasspoole has been able to contribute to the discussion and I would only make the following points:

(a) Dr Glasspoole writes 'percentages of annual rainfall averages are locally almost independent of orography'. I would be inclined to add 'provided that the mixture of weather types during the year is not too far from the average'. The question of using the percentage observed at one station to estimate that at another is important in any attempt to homogenize long-period rainfall records, and I would ask Dr Glasspoole whether he knows of any work which puts figures to the relationship, and limits to the residual error. His paper with Mr Salter[1] goes part of the way, but more is needed if we are to make the best of the earliest records.

(b) My latest provisional calculations of the percentage annual rainfall totals in 1872 for individual stations in 11 districts, where there percentages are based on averages over all available years for each station, give the following values:

Exeter 148·5; Ross-on-Wye 131·8; Oxford 113·5; London 134·3; Thwaite, Suffolk 119·7; Pode Hole, Lincs. 133·1; Mickleover, Derbys. 145·8; Leeds 154·1; Liverpool, Bidston 159·8; Kendal 137·3; and Carlisle 120·0. My figure of 159·8 for Liverpool, Bidston is based on a normal of 28·58 in, the actual average there for the 103 years, 1867–1969, and agrees with the 159 per cent given by Reynolds.[2] Incidentally, this is the third highest of 1584 such values which I have found for the 11 areas for each year from 1830 to 1973, and suggests that the probability of the annual rainfall total at one station exceeding 160 per cent of the normal there is about 1/528. The 11-area average for 1872 is about 136 per cent, the highest for any year from 1725 to 1973 compared with the figure of 144 per cent given by Dr Glasspoole in his 1928 paper.[3]

(c) It is true that Reynolds[2] refers to Bidston as being in the shadow of Snowdonia, although Doodson and Bigelstone[4] and Zoch[5] do not seem to have realized its relevance, but the point we were trying to make is that 1872 was a year in which the days when Bidston received the benefit of this protection were much fewer than usual, whereas the days in which the rain came from other directions were more numerous. Thus Bidston should be outstandingly wet in what was in any case an extremely wet year, and this is just what is shown by the above figures for the 11 districts.

(d) Dr Glasspoole will be pleased to know that I hope to continue to work on this subject, using both statistical and cartographic methods, when I join him in retirement. I think, however, that it is most important in these days of electronic computers, to quote the original data worked on wherever possible. The scope for computerized analysis is so great, compared with earlier methods, that a new experiment is always liable to cast doubt on some previous results, which then have to be tracked back to source.

Synoptic Climatology Branch,
Meteorological Office,
Bracknell, Berks.

J. M. CRADDOCK

REFERENCES

1. SALTER, C. and GLASSPOOLE, J.; Fluctuations of annual rainfall over the British Isles considered cartographically. *Q J R Met Soc, London*, **49**, 1923, pp. 207–225.
2. REYNOLDS, G.; Rainfall at Bidston, 1867–1951. *Q J R Met Soc, London*, **79**, 1953, pp. 137–149.
3. GLASSPOOLE, J.; Two centuries of rain. *Met Mag, London*, **63**, 1928, pp. 1–6.
4. DOODSON, A. T. and BIGELSTONE, H. J.; The frequency distribution of rainfall at Liverpool Observatory, Bidston. *Q J R Met Soc, London*, **60**, 1934, pp. 403–411.
5. ZOCH, R. T.; On the frequency distribution of rainfall at the Liverpool Observatory. *Q J R Met Soc, London*, **62**, 1936, pp. 421–428.

NOTES AND NEWS

Symposium on Weather Radar and Water Management

A symposium with the above title will be held from 15 to 18 December 1975 under the auspices of the Water Research Centre and the Royal Radar Establishment (RRE). It will be based at the Grosvenor Hotel, Chester, and will include field visits in North Wales and a visit to RRE at Malvern.

The symposium will report the use of radar for rainfall measurement, real-time applications of radar derived data and the importance of radar networks to rainfall forecasting. The work described arises out of the Meteorological Office/RRE Weather Radar Network Project, the Dee Weather Radar Project and the Dee Hydrological Forecasting Project. Organizations involved in these projects include the Central Water Planning Unit, Institute of Hydrology, Meteorological Office, Plessey Radar Ltd, Royal Radar Establishment, Water Data Unit of the Department of the Environment, Water Research Centre, and the Welsh National Water Development Authority.

Speakers from the Meteorological Office will include Dr T. W. Harrold and Mr C. G. Collier.

Further information may be obtained from Mr C. F. Cooper (on attendance) or from Mr J. A. Cole (on technical contributions) at

Water Research Centre,
Medmenham Laboratory,
P.O. Box 16, Ferry Lane,
Medmenham,
Marlow,
Buckinghamshire SL7 2HD,
ENGLAND.
Telephone: Hambleden (Bucks) 531 (049 166 531 on STD)
Cables: Water, Marlow.

OBITUARY

It is with regret that we have to record the death of Mr A. W. Carmichael, Higher Scientific Officer, Glasgow Airport, on 20 April 1975.

THE METEOROLOGICAL MAGAZINE

VOL. 104 NO. 1237 AUGUST 1975

CONTENTS

Page

Intensity–time profiles of high-intensity rainfall. J. R. Norbury and W. J. K. White 221

A note on tropical storms in the Arabian Sea, October to December 1972. R. A. Ebdon and W. J. Oxley 227

Optimum averaging time of wind reports for aviation. M. J. O. Dutton 231

Annual duration of any rainfall intensity. M.C. Jackson .. 243

Review

New Science in the solar system. P. Stubbs, editor. *A .H. Cook* .. 248

Letter to the Editor 249

Notes and news

Symposium on Weather Radar and Water Management 252

Obituary 252

NOTICES

It is requested that all books for review and communications for the Editor be addressed to the Director-General, Meteorological Office, London Road, Bracknell, Berkshire, RG12 2SZ, and marked 'For Meteorological Magazine'.

The responsibility for facts and opinions expressed in the signed articles and letters published in this magazine rests with their respective authors.

Complete volumes of 'Meteorological Magazine' beginning with Volume 54 are now available in microfilm form from University Microfilms Ltd, St. Johns Road, Tylers Green, High Wycombe, Buckinghamshire, England.

Full size reprints of out-of-print issues are obtainable from Johnson Reprint Co. Ltd, 24–28 Oval Road, NW1 7DX, London, England.

Issues in Microfiche starting with Volume 58 may be obtained from Johnson Associates Inc., P.O. Box 1017, Greenwich, Conn. 06830, U.S.A.

© *Crown copyright* 1975

Printed in England by Heffers Printers Limited, Cambridge
and published by
HER MAJESTY'S STATIONERY OFFICE

40p monthly **Annual subscription £5.46 including postage**

Dd. 289060 K16 8/75 ISBN 0 11 723075 8